IRRIGATION IN INDIA

INDIA OF TO-DAY

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IRRIGATION IN INDIA

BY

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PREFACE

The author desires to express his acknowledgments to the Government of India for permission to reproduce in this volume portions of the matter compiled by him, as Assistant Inspector-General of Irrigation, for the official Triennial Review of Irrigation in India, 1918-1921.

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PART I

GENERAL INFORMATION

CHAPTER I

The Necessity for Irrigation

No review of irrigation in India, however brief, would be complete without some reference to the meteorological conditions which render such irrigation necessary. The vast extent of the country precludes more than a general outline of these conditions being given, but even an outline will serve to show why, over a great portion of the peninsula, successful cultivation cannot be assured for any considerable period unless facilities are available for the artificial watering of the crops, when necessary.

The chief characteristics of the Indian rainfall are its unequal distribution over the country, its irregular distribution throughout the seasons and its liability to failure or serious deficiency. India, indeed, probably presents a greater variety of meteorological conditions than any area of similar size in the world. The normal annual rainfall varies from 460 inches at Cherrapunji in the Assam hills to less than three inches in Upper Sind. The greatest rainfall actually measured at any station in any one year was 905 inches, recorded at Cherrapunji

in 1861, while at stations in Upper Sind it has been *nil.* There are thus portions of the country which suffer as much from excessive rainfall as others do from drought.

The second important characteristic of the rainfall is its unequal distribution throughout the seasons. Except in the south-east of the peninsula, where the heaviest precipitation is received from October to December, by far the greater portion of the rain falls during the south-west monsoon, between June and October. During the winter months the rainfall is comparatively small, the normal amount varying from half an inch to two inches, while the hot weather, from March to May or June, is practically rainless. Consequently it happens that in one season of the year the greater part of India is deluged with rain and is the scene of the most wonderful and rapid growth of vegetation ; in another period the same tract becomes a dreary sunburnt waste. The transition from the latter to the former stage often occurs in a few days.

But from the agricultural point of view, undoubtedly the most unsatisfactory feature of the Indian rainfall is its liability to failure or serious deficiency. The average annual rainfall over the whole country is about 45 inches, and there is but little variation from this average from year to year, the greatest recorded being only about seven inches. But if separate tracts are considered, extraordinary variations are found. At many stations annual rainfalls of less than half the average are not uncommon ; while at some, less than a quarter of the normal amount has been recorded in a year of extreme drought.

The effect of these variations, as productive of famine and scarcity, differs considerably according to the average rainfall of the tract, being least in those parts where the average is either very high or very low. Where the average rainfall is high, a large deficiency can be experienced and yet sufficient water remains to ensure successful agriculture ; where the average is very low, ten inches or less, cultivation without irrigation becomes in any case practically impossible and agriculture consequently ceases to

depend upon the rainfall and relies wholly upon water obtained from other sources. In portions of such tracts which are devoted to pasturing cattle, high prices or the drying up of natural grasses may lead to distress, but famine from failure of crops need not be apprehended. But between these extremes, in which the crops are rendered safe either by an assured and abundant rainfall or by exclusive reliance upon irrigation, there lies a vast area, in which the average rainfall varies between 75 and 10 inches, no portion of which can be deemed absolutely secure against the uncertainties of the season and the scourge of famine.

In general it has been found that the lower the rainfall in a tract, the greater is its liability to serious deficiency from the average, and the most precarious area is that in which the normal rainfall is less than 50 inches. This area includes practically the whole of the Punjab and the North-West Frontier Province, the United Provinces except the submontane districts, Sind, a large portion of Bihar, most of Madras, most of the Bombay Presidency except a strip along the coast, portions of the Central Provinces and a small tract in Burma.

There are, however, other factors which govern the introduction of irrigation, the most important being an adequate water supply. The high-lying rocky plateau, which forms the interior of the peninsula, is very unfavourably situated in this respect, having an uncertain rainfall, rivers which, for much of the year, are nearly dry, a scanty population and but little agriculture as compared with that which flourishes in the alluvial tracts. Something has been done, by the construction of reservoirs, to conserve the monsoon rainfall and extend its benefits over the other seasons of the year, but by far the greater portion of this central plateau must, for want of water, remain for ever unirrigated.

If, therefore, it were desired to construct a map of British India so as to show, with due reference to the possibility of obtaining water, where irrigation is most

needed, it would be necessary to block out all parts where the average rainfall exceeds fifty inches, all tracts lying at a higher altitude than a thousand feet above the sea, and all Indian State territory. The remainder is the precarious area of British India; it comprises a great crescent of land extending from Karachi through Sind, the Punjab, the United Provinces and almost up to the boundary between Bihar and Bengal, a wide strip down the East Coast from Cuttack to Cape Comorin, and considerable island portions of Gujarat, the Central Provinces and Burma. It is in this area that the major irrigation works of India are to be found.

It will, of course, readily be realized that there are degrees of insecurity within the tract, but the whole of it is liable to famine. In general it may be said, as regards all the area within the 50-inch rainfall contour, that a deficiency of 25 per cent. below the normal rainfall will cause some injury, while a deficiency of 40 per cent. will cause serious scarcity. It is true that, in a tract where the normal rainfall is 45 inches, a deficiency of 40 per cent. will still leave 27 inches, while the same deficiency on a rainfall of 25 inches will leave only 15; but in the former case rice, which needs great quantities of water, will almost invariably be the prevailing crop, while in the latter it will consist of cotton or millet, for which less than half the amount is required.

Classing a year in which the deficiency is 25 per cent. as a dry year and one in which it is 40 per cent. as a year of severe drought, the examination of past statistics shows that, over the precarious area, one year in five may be expected to be a dry year and one in ten a year of severe drought. It is largely in order to remove the menace of these years that the great irrigation systems of India have been constructed.

CHAPTER II

The Classification of Government Irrigation Works

The Government irrigation works of India may be divided into two main classes: those provided with artificial storage, and those dependent throughout the year on the natural supplies of the rivers from which they have their origin.

In actual fact, practically every irrigation work depends upon storage of one kind or another but, in many cases, this is provided by nature without man's assistance. The distribution of the Indian rainfall is such that, without such storage, the majority of the rivers of India would be dry for more than half the year. But, except in the most rocky catchments, nature affords storage in the shape of the soil which absorbs a certain proportion of the rainfall and releases it gradually during the drier months, while, in Northern India, the snowfields and glaciers of the Himalayas hold up water on a scale which man cannot hope to rival. The storage afforded by soil absorption is, of course, very limited and consequently, throughout the peninsula proper, artificial storage is necessary if a continuous supply of water is to be assured, except in the case of the very largest rivers where the catchments are so great that the drainage from them is sufficient to maintain a supply, albeit usually a very meagre one, throughout the year. Thus, for example, the Kistna, which drains nearly 100,000 square miles of country and discharges in flood time one and a quarter million cubic feet of water a second, dwindles during the hot weather to a small stream, winding among sandbanks and carrying a quite inconsiderable volume.

It is consequently in Northern India, upon the Himalayan rivers, and in Madras, where the cold weather rains are even heavier than those of the south-west monsoon, that the principal non-storage systems are

found, although, in the latter case, there is a period of almost complete drought in the rivers during the hot weather. In the Himalayan rivers there is water and to spare during the monsoon; during the early cold weather the saturated hills gradually give up their moisture, thereby maintaining the supply, and the winter rains usually supplement this source to some extent. The volume, however, continues to fall rapidly until a minimum is reached, generally about February, when the approaching hot weather commences to melt the snow and a rapid increase is experienced which lasts till the break of the following monsoon. From rivers such as these a supply of water sufficient to support cultivation can be relied upon throughout the year.

The canals which rely solely upon the natural flow of the rivers for their supplies may be divided into two main types, perennial canals and inundation canals. Perennial canals are provided with some arrangement in the vicinity of their heads, usually in the form of an obstruction across the bed of the parent stream, by means of which they are enabled to obtain their supplies irrespective of the level of the water in the river. The water is, by means of this obstruction, ponded up to the height required in the canal, and seasonal fluctuations in the water level in the river are thus counteracted. The obstruction usually takes the form of a weir or barrage fitted with shutters and sluices whereby surplus water, not needed in the canal, can be escaped down the river.

Inundation canals, on the contrary, have no such weirs and their supplies fluctuate with the natural water level in the river. When this rises, the level in the canal rises, when it falls, the level in the canal falls with it. Generally speaking, inundation canals obtain a supply only when the parent stream is in flood and the adequacy or otherwise of this supply, and therewith the area irrigable in the year in question, is consequently solely dependent upon the seasonal conditions. There may be an ample volume in the river but, in the absence of any method of raising its level, it cannot be forced into

the canal until the water rises, of its own accord, to a sufficient height.

It may possibly be asked why, in view of the advantages to be obtained thereby, all canals have not been made perennial. The answer is : expense. The majority of, and by far the most important, inundation canals are to be found in Sind and the Punjab on the Indus and Sutlej Rivers. The task of harnessing these great rivers is only now being taken in hand ; it is proposed to construct a barrage across the Indus, at a cost of £5,700,000, and four across the Sutlej, at a cost of £3,850,000, and by linking up a number of the existing inundation canals to each barrage, to afford to them an assured and controlled supply. It is fully recognized that inundation irrigation cannot be regarded as other than an inefficient substitute for perennial irrigation and steps are therefore being taken, wherever possible, to supersede it by the latter class.

The expedient of storing water in the monsoon for utilization during the subsequent dry weather has been practised in India from time immemorial. In their simplest form, such storage works consist of an earthen embankment constructed across a valley or depression, behind which the water collects, and those under Government control range from small tanks irrigating only a few acres each to the huge reservoirs now under construction in the Deccan which will be capable of storing over 20,000 million cubic feet of water. By gradually escaping water from a work of the latter type, a supply can be maintained long after the river, on which the reservoir is situated, would otherwise be dry and useless.

CHAPTER III

The Extent and Growth of Irrigation

It must, of course, not be thought that, in those tracts where irrigation is scanty or altogether impossible, no cultivation takes place. This is very far from the truth. Throughout India, except in its most arid parts, agriculture is the main industry and enormous areas are cropped annually with no source of water supply other than the natural rainfall. In point of fact, of the total area cropped annually in British India, less than a quarter is artificially irrigated and the remainder is wholly dependent upon the rainfall; as regards the irrigated portion, about 11 per cent. of the total cropped area is irrigated from Government works, about 5 per cent. from wells, and about 6 per cent. from other sources, mainly small private tanks.

In this connection it must, however, be remembered that the benefits of any large irrigation work extend considerably further than the area irrigated in each individual year. Except in tracts such as Sind, where cultivation without irrigation is practically impossible, canals are usually so designed as to irrigate annually from one-third to one-half of the culturable area commanded by them and the various portions come under irrigation in turn, the remainder lying fallow or being sown with the more drought-resisting crops. But the whole area benefits from the rise of the sub-soil water level due to the introduction of irrigation and from the additional moisture of the air, and it is probably fairly correct to say that the area benefited by canal irrigation is some two and a half times the area actually irrigated annually. Looked at in this light, some 25 per cent. of the whole cropped area in British India is benefited and protected by Government irrigation works.

There has, during the last forty years, been a steady growth in the area irrigated by these Government works. From 10½ million acres in 1878-79 the area annually irrigated rose to 19¼ million acres at the beginning of the century and to 28 million acres in 1919-20, the record

year up to date, from which figure it fell again to 27 million acres in 1920-21.

Some idea of the probable future development of irrigation can be obtained from the forecasts appended to the project estimates of the works now under construction and awaiting sanction. The area irrigated in 1919-20 was, as has already been stated, over 28 million acres. Schemes completed but which have not yet reached their full development are expected to add about 100,000 acres to this total, while works under construction will further enhance it by 4 million acres. Projects have also been submitted to the Secretary of State for sanction which, if constructed, will add another 3¼ million acres ; a total eventual area in British India of about 36 million acres is thus at present contemplated from works sanctioned or awaiting sanction, irrespective of the natural extension of existing areas and of new projects, of which several are under consideration, which may be put forward in future.

The figures given above are exclusive of the areas irrigated from the Punjab canals by branches constructed for Indian States, which amounted in 1919-20 to 650,000 acres. The Sutlej Valley Project, which has recently been sanctioned, will add nearly 3¼ million acres to this area, so that a gross total of some 40 million acres from Government works is confidently looked to.

Perhaps, however, the easiest way of visualizing the growth of irrigation is by reference to the mileage of channels. In 1900-01, 39,142 miles of Government channels were in operation ; by 1920-21 this length had increased to 55,202 miles, a length more than sufficient to girdle the earth twice. This connotes an average addition of about 800 miles of channel every year.

Finally, the general financial returns may be looked at. Since the beginning of the century there has been considerable activity in almost every province and the

total capital invested in the works has risen from £42 million in 1900-01 to £79 million in 1920-21, an average increase of £1¾ million a year. As regards revenue, the Government irrigation works of India, taken as a whole, yield a return of from 7 to 8 per cent. on the capital invested in them ; this is a satisfactory result as nearly £12 million of the total have been spent on purely protective works which return less than 1 per cent. and £7 million on minor works, the yield from which varies between 4 and 6 per cent. The capital outlay also includes expenditure on a number of large works under construction, which have not yet commenced to earn revenue. It follows that, besides increasing the yield of the crops, making agriculture possible in tracts where, without an assured supply of water, nothing would grow, and protecting large areas from famine and scarcity, the irrigation works of India form also a remunerative investment for the funds sunk in them.

CHAPTER IV

Irrigation Administration

The basis of the Irrigation Administration of India is co-operation between Government and the cultivator. Up to a certain point Government retains control ; beyond that point matters are left to the users of the water. The headworks of the canal, the main line and branches, the distributaries and minor distributaries, are all constructed and maintained by Government, but the field channels or watercourses, by means of which the water is finally conveyed on to the fields, are usually constructed and invariably maintained by the cultivators themselves. Water is emitted from the Government canals through outlets built in their banks, and it is in general at these outlets that the responsibility of Government ends and that of the cultivator begins.

The responsibility for the distribution of water is similarly shared between Government and the irrigators, the former distributing the water as far as the outlets, and the latter doing the final distribution from the watercourses to the various fields. In cases in which a watercourse is shared between two or more cultivators and they are unable to agree as to an equitable distribution of the water between them, a right of appeal lies to the Irrigation Officer who can then step in and enforce suitable arrangements for the sharing of the supply.

The charges for water are levied in different ways in the various provinces. In some, notably in Sind, the ordinary land revenue assessment includes also the charge for water, nine-tenths of this assessment being regarded as due to the canals. In others, as in parts of Madras and Bombay, different rates of land revenue are assessed according to whether the land is irrigated or not, and the assessment upon irrigated land includes also the charge for water. These methods may, however, be regarded as exceptional. Over the greater part of India water is paid for separately, the area actually

irrigated is measured, and a rate is charged per acre according to the crop grown. Lower rates are often levied in cases where irrigation is by "lift," that is to say, where the land is too high for the water to flow on to it by gravity and consequently the cultivator has to lift it on to his field.

Various other methods of assessment have been tried, such as by renting outlets for an annual sum, or by charging according to the volume of the water used, but these have never been successful. The cultivator fully understands the principle of 'No crops, no charge' which is now followed as far as possible in canal administration, but has no confidence in a system under which his liability for water rate is independent of the area and quality of his crop.

The rates charged vary considerably with the crop grown, and are different in each province and often upon the several canals in a single province. Thus in the Punjab, they vary from 15 to 24 shillings per acre for sugarcane to from four shillings to six shillings and six pence per acre for millets and pulses. No extra charge is made for additional waterings. Practically speaking, Government guarantees sufficient water for the crop and gives it as available. If the crop fails to mature, or if its yield is much below normal, either the whole or part of the irrigation assessment is remitted. Taken as a whole, irrigation is offered on extremely easy terms, and the water rates represent only a very small proportion of the extra profit which the cultivator secures owing to the water he receives.

In most of the provinces, with the exception of Madras, Sind, and parts of Bombay, the distribution of the water and the assessment of the revenue form part of the duties of the engineers of the Public Works Department. The system under which engineers are entrusted with the revenue management of the canals may, at first sight, appear anomalous, but it has been amply justified by results, and the Indian Irrigation Commission of 1901-03 strongly advocated its retention. "As regards Northern India and Bengal," they reported,

" we certainly do not recommend any change in the existing system of management. We fully recognise the importance of placing the large and important irrigation works in those provinces under a separate staff of irrigation officers, who should not only as engineers be capable of designing, constructing and maintaining the works, but who should also be trained in revenue management, and devote all their energies to the improvement of the distribution and to the interests of the cultivator. We think that the more closely they are connected with the work of assessment and remissions, and with the settlement of all questions connected with the internal distribution of water within the villages on which a reference is necessary to external authority, the more progressive and sympathetic will be the administration."

PART II

A BRIEF HISTORY OF STATE IRRIGATION IN INDIA

CHAPTER I

Early Improvements of Indigenous Works

In the early records of the peoples of India, dating back to many centuries before the commencement of the Christian era, there are frequent references to the practice of irrigation. Wells have been in use from time immemorial and most of the almost innumerable tanks which are found in Southern India have been in existence for many generations; two, in the Chingleput District of Madras, which still irrigate a considerable area, are referred to in inscriptions of the eighth and ninth centuries. The practice of drawing off the flood waters of the Indus for the irrigation of Sind and parts of the Western Punjab has been followed from a very early date. In the submontane districts of Northern India are sometimes to be found the vestiges of ancient irrigating channels which have been buried for centuries in the undergrowth of the forests; in some cases, as in Rohilkhand, these remains have formed the basis of new and modern systems. There are also a large number of old indigenous tanks and river works in Burma. Little, however, was done in the direction of the construction of large works before the country came under British rule, the most notable exceptions being the Grand Anicut across the Cauvery in Madras which, until the end of last century, continued to act as a river surplusing work at the head of the Cauvery delta canals, some of the inundation canals from the Indus, two canals from the Jumna, which were the origin of the present Western and Eastern Jumna

Canals, and the Hasli Canal from the Ravi, which has since been replaced by the Upper Bari Doab Canal.

It is not surprising that the first efforts of the British engineers should have been directed to the improvement of the existing indigenous works rather than to the construction of new irrigation projects. Three of these improvement schemes, which were taken in hand early in the last century, are specially worthy of note, since they have resulted in three of the most lucrative systems in India, these being the Western Jumna Canal in the Punjab, the Eastern Jumna Canal in the United Provinces and the Cauvery Delta System in Madras. A short description of the first and last mentioned works is given below, as they illustrate clearly the difficulties with which the early engineers had to contend, and the setbacks which had to be encountered before irrigation science was brought to its present stage.

The origin of the Western Jumna Canal is shrouded in antiquity. The first record of an irrigation project in the Jumna Valley is that of a canal, built by Feroz Shah about the middle of the fourteenth century, with its terminus at Hissar, but whether it derived its supply from the Jumna or from the Chautung Nala, a stream further to the west and now merely a dry depression, is uncertain. As the main object of the work was to convey water to the Emperor's hunting lodge at Hissar rather than to irrigate the intermediate country, advantage was taken, in fixing the alignment, of any natural hollow or channel whose slope and direction were found suitable, and the resulting work consequently took the form of a linked series of drainages rather than of a canal, as the word is understood to-day.

About 1568, the channel, which had fallen into disuse, was renovated by Akbar, the object being, in this case, the irrigation of the Hissar District, which the Emperor was bestowing upon his son, Muhamad Salim. "God has said, from water all things are made. I consequently ordain that this jungle, in which subsistence is obtained

with thirst, be converted into a place of comfort." Thus ran the *Sanad* in which the renovation was ordered, and once again, after an interval of a century, water was conveyed by the canal to Hissar. Sixty years later further remodelling became necessary, and in 1626 this was carried out under the direction of Ali Mardan Khan, Shah Jehan's great engineer; in connection with it a new branch was constructed to convey water to supply the fountains of the Imperial palace and to adorn the streets of the rising city which the Emperor was erecting at Delhi. The maintenance of the supply, however, required constant labour and a greater degree of attention than was likely to be accorded to it amongst the pressing cares of a falling empire. The canal ceased to flow about the middle of the eighteenth century and remained in disuse until reopened by the British.

In 1821 a small instalment of the waters of the Jumna was again diverted into the Delhi canal by Lieutenant Blane of the Engineers, but the experiment was mistrusted both by Government and by the population of the tract affected, funds were severely restricted and the original alignment was consequently adhered to for reasons of economy, natural channels continuing to be utilized as far as possible and depressions being crossed on earthen banks with no adequate provision for the intercepted drainage. Swamps, as was to be expected, formed upstream of the canal, while the occasional collapse of the banks resulted in widespread injury to the villages and crops in the vicinity. The famine of 1832-33 led to the enlargement and multiplication of the irrigating channels, but these were executed in haste upon imperfect information and on bad alignments. Altogether the early history of the Western Jumna Canal is one of dearly bought lessons in hydraulic engineering. No check was put on over-irrigation, and between this fact and the faulty design of the canal itself large portions of the commanded tract became water-logged. Saline efflorescence made its appearance and there were yearly epidemics of malaria.

In 1873 the remodelling of the canal as a whole was taken in hand; the old alignment was improved and, in its

lower reaches at least, the Western Jumna Canal is now entitled to be ranked as a modern irrigation work. A permanent weir across the Jumna was constructed at Tajawala, by means of which the water is diverted, through a regulator, into the western branch of the river which serves the purpose of a canal for the first thirteen miles. At this point it is joined by the Somb and Pathrala torrents and a dam at Dadupur across the combined stream directs it into the excavated channel. The main canal and the Delhi branch have been re-aligned for a great part of their course, and drainage works have been freely introduced. The Sirsa branch, the largest branch of the canal, was added in 1889-95, and the whole system, from being a standing reproach, is now an unmixed blessing to the countryside. Over 2,000 miles of main canals and distributaries are in operation and, in 1919-20, 855,000 acres were irrigated, returning 11¼ per cent. on the capital outlay of £1¾ million.

The Cauvery Delta System in Madras is of far greater antiquity than the two Jumna systems ; indeed, from the nature of the case, it is probable that artificial irrigation must have been contemporary with agriculture itself in the delta lands of Tanjore. About eighteen miles above the head of the delta the Cauvery is divided by the narrow island of Srirangam into two channels, the Cauvery proper on the right and the Coleroon on the left, the Cauvery being the high level and the Coleroon the low level channel of the river. The Coleroon flows in an almost direct course to the sea ; the Cauvery, on the other hand, below the island, divides and subdivides into innumerable branches which form a network of distributaries over the delta, some ultimately finding their way to the sea while others are lost in the wide expanse of rice fields.

To prevent the water of the Cauvery branch from flowing back into the Coleroon, the tail of the island of Srirangam is connected with the left side of the Cauvery Delta by means of a masonry weir, known as the Grand Anicut. The original work, constructed of stones laid

in clay, is generally ascribed to a period corresponding to the second century of our era, and for some sixteen hundred years it must have withstood floods by the mere inertia of its materials. It consisted of a solid mass of rough stones, of moderate size, 1,080 feet in length, from 40 to 60 feet in breadth and from 15 to 18 feet high, spanning the space between the island and the delta in serpentine form, a favourite mode of construction in ancient hydraulic works, and adopted under the impression that, as all natural watercourses are tortuous, all artificial works in water ought to be the same. There were no sluices in this weir through which supplies not required for irrigation could be escaped, and the delta channels were thus called upon to serve alternatively as distributaries and flood carriers, the distribution system being accompanied by a widespread system of embankments to protect the irrigated area from the destructive effects of an excess of water.

Such was the condition of affairs on the cession of Tanjore to the British in 1801, but the position was gradually becoming unstable as the Coleroon, with the larger flood volume, the steeper slope and the more direct course threatened continually to take a greater and greater proportion of the water, leading to the deterioration of the less favourably situated Cauvery branch and to the formation of shoals at its head. As early as 1804 it was recognized that, unless measures were adopted to rectify, by artificial means, the natural differences between the two branches, the annihilation of the Cauvery as an irrigating channel, and, as a result, the ruin of Tanjore, was an inevitable consequence. For some 30 years an incessant struggle was maintained against the increasing tendency of the Cauvery to silt up, including the construction of sluice-ways in the Grand Anicut, but the measures adopted proved ineffective, being directed against the symptoms rather than the cause of the evil.

In 1834 proposals for the establishment of a stable regime were put forward by Major (afterwards Sir) Arthur Cotton, who advocated the construction of a permanent masonry weir across the Coleroon at the head of Srirangam

Island, of such a height as to divide the supply in the river equitably between the two branches. His proposals were accepted and the work, known as the Upper Anicut, consisting of a simple bar of masonry 2,562 feet in length and between 5 and 7½ feet high resting on wells, with an apron in rear, was carried out in 1836. Twenty-two small sluices were distributed throughout the length of the weir in order, by permitting the free passage of sand, to prevent the bed of the Coleroon being raised by deposits.

Experience showed, however, that the full effect of the construction of the weir had not been clearly realized by its designer. The sluices proved utterly inadequate, and the bed of the Coleroon upstream rose gradually till it was level with the top of the work. The excess volumes passed into the Cauvery led to great erosion of the banks and deepening of the bed of that branch and threatened to make the Cauvery instead of the Coleroon the main flood-carrier of the river, with results disastrous to Tanjore. Consequently, in 1843-45, it became necessary largely to increase the sluice-ways in the Upper Anicut, to lower its crest in a considerable portion of its length and to construct a masonry bar, known as the Cauvery Dam, across the head of the Cauvery branch to obviate further retrogression in its levels. These works proved successful and remained in operation till the end of last century, the only important additions being the construction of regulating bridges for the Cauvery and Vennar, the two main irrigating channels, below the Grand Anicut in 1888 (the head of the Vennar being moved three miles downstream of the point where it was formerly situated) and the fitting of falling shutters on the Grand Anicut to enable a larger supply to be forced into the two channels. In 1899-1902 the whole system of weirs was remodelled, long lift shutters, 6 and 5 feet high respectively, were installed on both the Upper and Grand Anicuts, the crest level of the former being cut down by four feet, and complete control, both of the supplies and of the diversion of the river flow, was thus obtained. The Upper Anicut now consists of 55 bays each of 40 feet span, the Grand Anicut of 30 bays each of 32 feet span.

The average area irrigated by the Cauvery was, prior to the construction of the Upper Anicut in 1836, about 600,000 acres ; this has now expanded to over a million acres and the works yield a return of more than 17 per cent. on a capital outlay of £450,000. The system comprises some 1,500 miles of main canals and branches, and nearly 2,000 miles of distributaries.

The three works mentioned in this chapter are of importance not only as works which are of the utmost benefit to the tracts which they affect but as the three first lessons taught in India in hydraulic engineering on a large scale. Dyas in the Punjab, Cautley in the United Provinces and Cotton in Madras were each engaged on the canal under improvement in his own province and each carried the lessons he learnt with him when he proceeded to his first great original undertaking, Dyas to the Upper Bari Doab Canal, Cautley to the Ganges Canal and Cotton to the Godavari Delta System. True, mistakes were made even on these, but the enormous advance which they show over the earlier works, in which the problems were solved by methods of trial and error, of experiment and reconstruction, are proof of the value of these earlier, if often bitter, lessons.

CHAPTER II

THE GREAT CLASSIC IRRIGATION WORKS

As already stated, the experience gained by the British engineers on the two Jumna canals and on the Cauvery Delta System led directly to further investigations as to the possibility of extending river irrigation to other portions of India. In the northern provinces the fertile valley of Dehra Dun, between the Ganges and Jumna, was the first to attract attention and the small Dun canals came into being in the late thirties. Rohilkhand, a tract in the United Provinces, then came under the notice of Government. Rohilkhand had from time immemorial been the field of very extensive irrigation and still preserved vestiges of its ancient canals, dams and watercourses ; a " Superintendent of Canals and Embankments in Rohilkhand " was appointed in 1843, under whose direction two small canals were constructed in the Bijnor District, and to whom was entrusted the renovation and improvement of the old Rohilkhand canals. These schemes were, however, of a minor order, and it is to Colonel Sir Proby Thomas Cautley, of the Bengal Artillery, that India owes the conception of the first great wholly artificial canal constructed in Upper India. The Ganges Canal, Colonel Cautley's monumental work, still ranks among the largest in the world and has served, in many respects, as a model for those which have since been built. This canal, and the Godavari Delta System, a project of a different kind, are dealt with in this chapter ; considerations of space forbid more than a reference to the third great classic work, the Upper Bari Doab Canal in the Punjab, which followed close upon the Ganges Canal and which has converted the upper portion of the Ravi-Beas-Sutlej watershed in that province from a wild jungle into a richly cultivated countryside.

The surveys for the Ganges Canal were commenced in 1836, the first project was submitted in 1840, and ground was broken in 1842. From the beginning, however, the shadow of war lay heavy over the canal works, and neither

the attention of the higher authorities nor the funds required for the rapid prosecution of construction were forthcoming to any adequate extent. Originating as it did at the commencement of the Afghan War, the work progressed but slowly during the subsequent period of intense trouble in which the return of the armies from Afghanistan and fierce battles with the Mahratta Chiefs were the most remarkable events. Then followed the Sikh invasion, when the consequent demands upon the public purse and the withdrawal of the military engineer officers from the canal for active service again interrupted progress. The canal was eventually opened for irrigation in 1854 though a good deal of work still remained to be done, especially on the distribution system, work which was seriously hampered by the Mutiny of 1857. The full supply for which the canal was designed was first admitted during the famine of 1861-62, which date may be said to mark the completion of the work, though much remodelling has been done and many additions made since that time.

The canal draws its supply from the Ganges River at Hardwar, where it debouches from the hills, the water, prior to the construction of the new permanent headworks just completed, being forced into the western channel of the river upon which the head of the canal is situated by means of temporary weirs constructed of wooden crates filled with boulders. It was originally designed to carry 6,750 cubic feet per second, but can carry 8,000 when required, the width at the head being 200 feet and the depth, at full supply, nearly 11 feet.

The head reach of the canal, from the point where it leaves the river to the twentieth mile, may fairly be classed among the greatest feats of irrigation engineering in India. The alignment traverses the main drainage lines of the tract, and the arrangements for disposing of this drainage are complicated by the fact that the canal bed is at places far below and at others far above the general level of the surrounding country. Four large torrents have to be crossed in this reach, while several smaller ones are admitted direct into the canal. The rapid slope of the country,

moreover, necessitates the negotiation of over 60 feet of bed fall in these first twenty miles.

Up to the twelfth mile the canal is in deep cutting. In the sixth mile it encounters the Ranipur torrent, which is carried over it on a masonry superpassage, 200 feet wide and capable of taking a flood 14 feet deep. At the tenth mile the Pathri torrent is passed over the canal on a second superpassage, 300 feet wide and 14 feet deep. The declivity of the bed of the Pathri torrent above the superpassage is 25 feet a mile and enormous forces have consequently to be dealt with when the torrent is in flood. At the thirteenth mile the Ratmau torrent is passed across the canal, being admitted directly into the channel on one side and escaped again through a weir, fitted with falling shutters, which is built into the downstream bank. A regulator across the canal prevents excess water from flowing down the canal when the torrent is in flood.

At the nineteenth mile comes the Solani Aqueduct, which is indubitably the finest work on the canal. The aqueduct proper consists of fifteen arches, each of 50 feet span, supported on massive masonry piers, which carry the canal over the Solani River, the waterway provided for the canal being 10 feet deep and 164 feet in clear width, excluding the wall in the centre which divides the channel into two bays, and the roads on either side. The up and down stream continuations of the aqueduct take the form of an enormous earthen embankment across the valley of the Solani, over two and a quarter miles long, and 36 feet high from the ground to the canal roadway. The sides of the canal are revetted with masonry throughout the length of the embankment and for some distance below it, giving a total length of revetment of over three miles. Even viewed in the light of modern development, the Solani Aqueduct and its approaches must still be accounted as one of the most magnificent irrigation works ever constructed.

It cannot, however, of course be pretended that the design of the Ganges Canal was by any means perfect in

every respect. Indeed, no sooner was the full supply of the channel first admitted than it became apparent that there were several serious faults. The bed slope was in many places too great, the masonry falls were of a type which generated excessive velocities below them causing heavy scour in both bed and banks, and the general lay-out of the distributary system was much inferior to that adopted in modern practice. A very considerable amount of remodelling was necessary before these defects were removed, but in other respects the work remains to-day substantially as Cautley built it. When it is remembered that, at the time it was constructed, experience of artificial canals was limited to works of only about a third of the size of the Ganges Canal, the mistakes made appear insignificant when compared with the enormous advance in hydraulic engineering which the scheme represented, and the general soundness of its author's judgment was, considering the state of knowledge in his day, little short of marvellous.

The scope of the system has been considerably altered since it was first constructed. The Lower Ganges Canal, which was opened in 1878, intersected two of the main branches of the upper canal, and the tail portions of these are now included in the Lower Ganges System. In their place, however, three important new branches have been added to the upper canal. In the mileage of its channels, the Upper Ganges Canal is still the largest in India, the system comprising 568 miles of main canal and branches and 3,293 miles of distributaries, or 3,861 miles of channel in all. It irrigated 1,316,000 acres in 1919-20 and yielded a return of 11¾ per cent. on a capital outlay of £4 million.

While, however, great strides were being made in the matter of canal design, but little was being done in regard to the construction of permanent headworks. The two Jumna, the Ganges and the Upper Bari Doab Canals were all originally dependent for their supplies upon temporary arrangements, erected annually in the river bed ; only the Cauvery system had permanent diversion works and it was largely the success which

attended the construction of these which led Sir Arthur Cotton to propose a weir on the Godavari which was to be as great an advance on anything previously attempted in that line as the Ganges Canal was in the matter of canal construction.

The Godavari rises in the Western Ghauts only some fifty miles from the West Coast, whence it flows across the peninsula to discharge its waters into the Bay of Bengal. It receives the drainage from 115,000 square miles, an area greater than that of England and Scotland combined, and its maximum discharge is calculated to be 1½ million cubic feet a second. Towards the end of its course it pierces the Eastern Ghauts and eventually emerges into the plains of the Coromandel Coast. Small outlying hills, however, occur along its left bank for some twenty-five miles further; the last of these, which lies close to the river, is at Dowlaishwaram, where the Godavari has attained a width of four miles. It then divides into two branches, the Gautami Godavari being the Eastern and the Vasista Godavari the Western branch, and its delta begins.

The question of irrigating the delta from a weir in the neighbourhood of Dowlaishwaram was mooted as early as the end of the eighteenth century but it needed the spur of famine to stir the Government to action. The years from 1832 to 1841 were calamitous, containing four famine years and three of shortage, and in 1844 Sir Arthur Cotton was deputed to report on the subject. He strongly advocated the initiation of a comprehensive scheme for the irrigation of the delta, and the work was sanctioned in 1846 and put in hand under his executive control.

The work, as originally carried out, was as follows: On the left flank of the river was the head regulator of the Eastern Delta System, with a navigation lock and the connected under-sluices. Two weirs, the Dowlaishwaram Weir, 4,940 feet long, and the Ralli Weir, 2,859 feet long, joined by an embankment with its top 21 feet above the weir crest, spanned the Gautami Godavari. At the western end of

the Ralli Weir were the under-sluices of the Central Delta System, and a little beyond them the head regulator and navigation lock of that system. The Vasista Godavari was also crossed by two weirs, the Maddur and Vizeswaram Weirs, 1,548 and 2,598 feet long respectively, and from the right flank of the latter an embankment led to the under-sluices, head lock and head of the Western Delta System. The headworks thus comprised 11,945 feet or 2¼ miles of weir, 7,365 feet or nearly 1½ miles of embankments, three canal heads with navigation locks and three sets of under-sluices.

The magnitude of the work can be gauged from this brief description. It was without a prototype, except the weir on a much smaller scale which Major Cotton himself had built in the Tanjore District, and it was carried out in a place where no engineering works of any size had ever been constructed, with rude Indian labour and with apparatus which was generally of quite a primitive description.

The works have, it is true, been considerably altered and added to since they were built, both the designs and the calculations on which they were based being, as was inevitable in the circumstances of the case, by no means in accordance with the best modern practice. The weir was built too low in the first instance and has since been raised. By 1890, when the construction estimate was finally closed, two of the canal heads and all three head locks had been rebuilt to improved designs, and the original under-sluices on the Dowlaishwaram side were replaced, in 1910, by a modern set consisting of ten openings of 20 feet each. The design of the weir was such as to cause heavy action in the river bed and in 1895 it was reported that more than a million tons of stone, in addition to that used when constructing the weir, had had to be deposited below it in order to secure its safety. Yet, in spite of such errors, the construction of the weir was indubitably a great achievement, and a notable landmark in the history of irrigation in India, demonstrating, as it did, the possibility of harnessing for man's use the greatest and most formidable rivers.

The construction of a canal system in a deltaic tract is, of course, a much easier matter than in the broken country of Northern India. Briefly speaking, in the case of the Godavari two canals are so aligned as to mark the exterior boundaries of each section of the delta and branches have been taken from these to irrigate the country between them. An extensive system of drains to carry off surplus water has been provided, and the two branches of the river have been fully embanked on both sides so as to prevent floods from spilling over the cultivated country.

The Godavari Delta System has been of untold value to the tract it irrigates. The delta, which was formerly one of the areas most liable to famine, is now an expanse of paddy fields broken by gardens of fruit trees. Failure of crops is practically unknown and the main canals furnish an excellent means of transport. The system now comprises 500 miles of main and branch canals and 2,000 miles of distributaries; it irrigated close upon a million acres in 1919-20, and yielded a return of nearly 25 per cent. on a total capital outlay of £1½ million.

CHAPTER III

Other Works of the Fifties and Sixties

Owing to the vast extent of the country and to the fact that it is split up, for administrative purposes, into more or less self-governing provinces, each pursuing its own course, it is not altogether easy to divide the story of irrigation in India into well-defined periods. Some provinces went ahead, others lagged behind, and there was consequently no regular and even development. But the years from 1850 to 1870 may perhaps be held to constitute a self-contained period, as those in which the example, which had been so well set in Madras, the United Provinces and the Punjab, spread over the rest of India.

From the account of the operations of these years will, however, be omitted the history of the four great irrigation works which were inaugurated by private enterprise. The story of these projects, which were commenced in the sixties in a spirit of boundless optimism, and of the failure which attended them, will be told in a separate chapter.

Since the time of the conquest of Sind the great indigenous irrigation systems in that province had been attracting the attention of Government. The Mirs, although they had levied an additional tax on lands watered from the State canals, had discharged very imperfectly their duty of repairing and clearing the same, and the works were generally neglected and in some cases had fallen into disuse. These canals depend for their supply upon the river Indus. The majority of them take off direct from the main river while the remainder derive their water from flood spills, the only exception being the Eastern Nara System, for the purposes of which a natural valley, running roughly parallel to the Indus, has been connected with it by an artificial cut. The whole of the irrigation is, strictly speaking, by inundation, as no weir has yet been constructed across the Indus, but on the Eastern Nara System it is of a semi-perennial type, in that, while the supply of the Eastern Nara Channel itself fluctuates with the rise and fall of the main river, the supplies to some of the canals

upon it are controlled by weirs. Most of the canals which take off direct from the Indus obtain water only when it is in flood; one or two, however, are so fortunately situated as to be able to draw off a small volume even during the winter months.

The early administration of the canals by the British Government was unsuccessful, the officers responsible for them being quite ignorant of the subject, and it was not until the appointment of Sir Bartle Frere as Commissioner in 1851 that any real work of improvement was started. Thereafter, however, progress was rapid, and one after another the great inundation canal systems of Sind were restored, enlarged and brought into working order. Among the major works thus developed may be mentioned the Fuleli and Ghar Canals, each designed to carry 10,000 cubic feet a second, and effecting irrigation between them to the extent of 800,000 acres.

In the Bombay Presidency proper a beginning, albeit but a small one, was also being made and the possibility of irrigating parts of the arid Deccan plateau slowly realized. It was in this tract that the first Government storage work, the Mukti Tank, was constructed in 1869, which, although unimportant in itself, may be regarded as the prototype of the great reservoir schemes which have since been and are now being built to conserve the monsoon supplies of the Deccan rivers for use during the drier months.

It was, however, in Madras that the greatest progress was being made, the most important development being the construction of the Kistna Delta Project. The famine of 1832-33 had devastated this tract, while through the very heart of the area where the distress was greatest and human beings were dying by hundreds of thousands, because their crops had failed from drought, the Kistna was rolling down enormous quantities of water to the sea. This year was followed by several unfavourable ones, and consideration was given to all possible means of lessening the unmitigated dependence of the crops on the capricious

local rainfall. Accordingly, from time to time during the next few years, suggestions were made, and in some cases carried out, for channels from the main rivers to irrigate small areas of land, till at last, in 1839, a project—framed over forty years previously and apparently forgotten—for a comprehensive scheme of irrigation for the whole delta was again brought to notice. In 1840, however, it was decided that the very large and costly works necessary were "inexpedient and impracticable" and it was not until Sir Arthur Cotton, in 1844, proved in his report on the Godavari the feasibility of such works that the question was again taken up. A Committee of experts was appointed in 1848 to enquire into the matter and, on its unanimous recommendation that the work should be undertaken, the project was eventually sanctioned in 1851.

The Kistna, like the Godavari, rises in the Western Ghauts and flows across the peninsula into the Bay of Bengal. It drains over 97,000 square miles and, from its most distant source to the sea, it is approximately 800 miles in length ; its maximum discharge, on entering its delta, is about one and a quarter million cubic feet a second which, however, dwindles to only 100 cubic feet during the hot weather. About 60 miles from its mouth it passes at Bezwada between two hills about three-quarters of a mile apart, and beyond this point, stretching away on both sides of the river, lies the alluvial plain it has formed, which bears the name of the " Kistna Delta," the tracts on either bank being known respectively as the Eastern and Western Delta.

The site chosen for the weir was at Bezwada where the river flows between two gneissic hills only 3,900 feet apart. The work was commenced in 1852, Captain C. A. Orr of the Madras Engineers being in executive charge. No better selection could possibly have been made, as Captain Orr had, under Sir Arthur Cotton, just successfully completed the great weir on the Godavari, after a four years' fight against difficulties which at times appeared overwhelming, and the extensive experience thus acquired was of the very kind most needed for the Kistna work.

Although the length of the latter was rather less than a third of that on the Godavari it was a formidable enough undertaking to construct a weir 15 feet high and almost three-quarters of a mile long in a gorge where the river bed was pure sand and where high floods rose 40 feet. And it was probably because of the extensive past experience which Captain Orr brought to the work that the history of its construction was comparatively uneventful and unmarked by the occurrence of serious failures. The work was pushed on rapidly and successfully completed in 1855.

The canal system consists of a main canal on either side of the river, with a network of distributing channels spreading over the whole delta, and is connected by a high level channel with the western high level canal of the Godavari System, thus completing the navigable line between the Godavari and Kistna.

Works in Madras were, however, by no means confined to the two great deltaic projects. From time immemorial, a vast area of irrigation had been effected in the Presidency from small canals and tanks, but in many cases the supplies of the latter were very uncertain. The Madras Government devoted particular attention to the improvement of this class of irrigation. In addition to the repair and renovation of existing tanks a number of new works were inaugurated, including weirs across many of the smaller rivers of the province designed both to give direct irrigation by means of canals taking off above them and to replenish the supplies of the small storage works in the commanded area. Collectively these small works are of considerable importance and contribute largely to the irrigated area of the Presidency.

CHAPTER IV

Madras and East India Irrigation Companies' Canals

The next chapter in the history of irrigation in India is an unfortunate one; a chapter of failures on almost as large a scale as the classic works have been successes. While Sir Arthur Cotton's skill as an engineer was beyond dispute, his ability as an administrator and a financier was by no means so high. In the early sixties, however, when he was at the summit of his fame, this latter fact was apt to be overlooked. Those in authority, who had at first been sceptical as to the success of his projects, had gradually been converted by the magnificent results attained, until they were ready to lend an ear to almost any scheme he might put forward. When, therefore, he advanced a proposal for a combined irrigation and navigation work which was to overshadow in magnitude all that had gone before it, he found many and enthusiastic followers. There was a "boom" in irrigation at the time and every new project appeared a potential gold mine.

Sir Arthur Cotton's proposals contemplated a vast system of canals radiating east and west from the Tungabhadra and Kistna. Four weirs were to be constructed on the Tungabhadra, one of the largest tributaries of the Kistna, and one on the Kistna itself. Storage reservoirs were to be built to impound over 50 thousand million cubic feet of water to maintain a navigation supply for the canals, a cut was to be made to divert part of the water of the Tungabhadra into the Penner, and five large canals were to be excavated. The improvement of over 600 miles of river channels for navigation purposes was also to be undertaken and, by means of a coast canal, a connection was to be made between the Kistna Delta and the town of Madras. On the west, a canal was to proceed 600 miles to Poona and to tap the west coast at Bhatkal, stretching out its arms from Ahmednagar in the north to the coast town of Mangalore in the south. It was anticipated that the project would open up 150,000 square miles of country, that it would affect a population of 10 million persons and involve an increased trade of five million sterling per annum. The total cost of the project was placed at about 2 million sterling.

But Sir Arthur Cotton's dreams did not stop even here. In a report of 1858 he recommended the construction of a huge irrigation and navigation system from Rajmahal on the Ganges, north of Calcutta, to irrigate from the Sonthal hills on the west to near Dacca on the east, while joining Calcutta with the Ganges by means of a navigable canal. He further foreshadowed the connection of this line by means of an artificial canal 550 miles long with the Ganges Canal at Cawnpore, completing a line of 1,200 miles to Hardwar, and the junction of this system, by means of a branch 200 miles long from the Ganges Canal, with the Sutlej River, thus uniting the system of navigation in the Punjab with that of the Ganges. The Orissa Canals, then under consideration, would give a further navigable line along the east coast which would be extended *via* the Kistna and Godavari Deltas and joined, through the Tungabadhra Project, with Madras and the west coast. In other words, he contemplated a navigable line, 4,000 miles long, from Karachi *via* Cawnpore, Calcutta and Cuttack to Bhatkal, Mangalore and Madras. "There is not a single obstacle to this," he wrote, "and the results would be far beyond any calculation." The latter part of the remark is certainly true, though probably not in the sense in which it was intended.

The history of the scheme is one of failure from beginning to end. Only the Cuddapah section, now known as the Kurnool Cuddapah Canal, was ever taken in hand. This section was estimated to cost £550,000, but long before it was completed the whole of the capital of the Company had been spent and work had thereafter to be carried on on a loan of £600,000 from the Secretary of State. On the completion of the section in 1871 the work had to be stopped for want of funds. The Company continued in existence until 1882, by which time, the revenue having failed year by year to cover the working expenses, its accounts showed a deficiency of over two million pounds. Of this, nearly a million pounds represented the interest guaranteed by the Secretary of State, which formed one of the first charges on the profits of the Company, £500,000 was owing on a mortgage which had been raised by the Company

on its property, £600,000 represented the unpaid balance of the Secretary of State's loan together with interest, and £50,000 irrecoverable advances of various sorts made by Government to the Company. Consequently, in order to avoid further liabilities, Government was compelled to buy out the Company for £1,185,500, in addition to which a dead loss, owing to debts abandoned, of over 1½ million pounds sterling was incurred. The Crown thus paid for an isolated fragment of the eastern system as much as had been estimated as the cost of the whole gigantic scheme.

The cause of this utter and lamentable failure of a scheme which was originally expected to pay over 20 per cent. is by no means difficult to determine. It was in no way due to the fact that the canal formed only a portion of a larger project, as Sir Arthur Cotton was convinced that, treated as a self-contained unit, it would prove highly remunerative. No attempt, however, appears to have been made to examine the soils in the area commanded, which consist largely of black decomposed trap which needs irrigation very rarely, is difficult to work when wet, and produces good crops with the average local rainfall. The cultivators in the tract had never practised irrigation, were not trained in it, and could grow what for them were fair crops even on their poor land without its aid in most seasons. Consequently the demand for irrigation has always been extremely small. Nor is there ever likely to be any notable return from navigation for the reason that the canal runs from nowhere to nowhere in particular, and consequently there is nothing and nobody to carry. A proposal to close the canal for navigation purposes is at present under consideration.

The Kurnool Cuddapah System consists of 414 miles of main canal and branches and 290 miles of distributaries. Its capital cost up to date has been £2⅓ million, to which must be added £3 million, being the accumulated arrears of interest on capital. It irrigates only about 70,000 acres, the receipts from which yield a net revenue of about £15,000 per annum, or about £65,000 less than the interest charges. The extraordinary oversight which led to the unhesitating construction of these great works

without regard to the character of the soil to be watered, to the people who owned it, or to the results to be obtained by its execution, is one of the most remarkable and at the same time most regrettable incidents in the history of Indian irrigation.

Space will not permit of a detailed description being given of the three great systems inaugurated at about the same time by another Company, the East India Irrigation and Canal Company. Two of these, the Orissa and Midnapur Canals, are part of one enormous scheme, but long before either of these components was completed it was found that the probable profits had been grossly overestimated and the connecting link between them was never built. As in the case of the Kurnool Cuddapah Canal, the funds of the Company were exhausted long before large portions of the project had even been started and Government were compelled to come to the rescue and take over the works. It is, however, only fair to say that, in spite of the enormous outlay upon them—some £2¾ million in capital which is swollen to over £7 million if arrears of interest are included—the Orissa Canals at least have, in one respect, justified their existence. Before their construction Orissa, shut in between pathless jungles and impracticable seas, and alternately visited by floods and drought, was always liable to terrible visitations of famine. The great famine of 1865-66, for example, which occurred before the canals were sufficiently far advanced to give material relief, cost the lives of a million people and the Government £1½ million to save the remainder. Prior to the works, the whole province depended upon one crop in the year; if this failed from excess or deficiency of moisture there was nothing but starvation before the people. Now there is a large extent of land commanded by the canals upon which one crop can be saved or another raised in its stead, while a still larger area is protected from floods by embankments constructed in connection with the system. The navigable canals, moreover, provide a means for the transportation of produce to regions of dearth. From a purely protective point of view, therefore, the works are of the greatest value.

The last of the systems to be inaugurated by the East India Irrigation and Canal Company were the Son Canals, but in this case the works were taken over by Government before commencement, owing to the failure of the Company, and were carried to completion, though on a much less ambitious scale than had originally been intended, by Government agency. Though the system has never been successful, the failure has been on a much smaller scale than in the case of the other three systems, and a return of about 5 per cent. on the capital outlay of £2¾ million is now being obtained. It irrigates twice the area irrigated by the Orissa Canals, which cost the same amount, and produces four times the revenue. It will, however, be many years before the heavy arrears of interest accumulated against it are wiped out.

It is at least curious that the four greatest failures in the history of Indian irrigation should all be works inaugurated by private enterprise. Government engineers have often been guilty of underestimating expenditure and overestimating revenue, but never to the same extent as the financiers and private professional men connected with the Madras and East India Companies. In these days, when each project is submitted to the closest scrutiny in every possible aspect before sanction is applied for, it seems incredible that the companies, in their desire to secure immediate profits, should ever have rushed into the schemes as they did, commencing construction long before the ultimate scope of the project was known, building works in haste only to abandon them at leisure as unsuitable, basing their estimates of returns on figures of gross areas commanded without reference to the need for irrigation, the soils or the character of the people affected and drawing rapid conclusions from what had been done elsewhere, ignoring altogether the different conditions obtaining. The present traditions of caution in examining any new project may be attributed largely to these failures. The collapse of the two companies further demonstrated convincingly that private enterprise, on the lines adopted, was an unsuitable agency for the execution and management of large irrigation works and led

to the acceptance by the Secretary of State in 1866 of the policy of supplementing the ordinary resources of Government by means of public loans for the construction of productive public works, the adoption of which policy has rendered possible the great development of canal irrigation in India which has taken place since that time.

CHAPTER V

The First Loan Works

The acceptance by the Secretary of State of the principle of financing productive works by loans raised in the open market naturally gave a great stimulus to the development of irrigation in India. The works already constructed had furnished a series of valuable lessons ; it had been clearly demonstrated that irrigation canals, if properly designed and situated, were extremely lucrative investments, while the failure of the Companies' canals had shown what to avoid. Moreover, for the first time, money was available in reasonable and regular amounts. The direct result of the new policy was the inauguration of five works of great magnitude and several smaller ones, the five larger being the Sirhind, Lower Ganges, Agra, Lower Swat and Mutha Canals.

The Sirhind Canal in the Punjab draws its water from the Sutlej above the junction of that river with the Beas and irrigates a wide stretch of land, part of which is British and part Indian State territory, lying to the south of the river. The first proposal for the canal contemplated the irrigation of the Patiala State lands only, and a project of this limited scope was actually prepared, but further consideration showed that a scheme for the service of so limited an area was unlikely to prove remunerative and in 1867 orders were issued by the Government of India for the preparation of a revised and extended project, the basic principle to be observed being that the waters of the Sutlej should be utilized to the best possible advantage in the tracts commanded, irrespective of territorial boundaries.

For the first three miles of its course the canal, which is 200 feet wide, is in heavy cutting, but thereafter it enters the trough of the Sutlej, a level, marshy, alluvial valley, through the soft material forming which the river has been accustomed, from time immemorial, to cut its channel at pleasure, wandering freely from one side to the other. For nine miles the canal had to be excavated through this spongy and saturated soil, where the sub-soil water level

was at times 20 feet above the bed of the canal. Work of this nature is of the utmost difficulty. Expensive cuttings were necessary to drain the springs exposed by the excavation, powerful pumps had to be employed to cope with the continuous influx of water and, even when the digging was complete, the task of keeping the channel open was by no means light. To add to the trouble, the greatest masonry works on the line occur in this reach of the canal.

The first of these is the Budki superpassage, the largest work of its kind in India. It carries two great torrents, the Sugh and Budki, with a combined discharge of 30,000 cubic feet a second, across the canal. The superpassage is 450 feet wide with parapets 14 feet high and is carried over the canal on seven arches, each of 31¾ feet span, which are supported by piers 8 feet thick. A little further down is the Siswan superpassage which, although not so large as the Budki, proved the most difficult work on the line to construct, the foundations being 20 feet below the sub-soil water level. There are seven spans of 37½ feet for the canal waterway; the superpassage is 250 feet wide between parapets, supplying a crossing place for 24,000 cubic feet of water a second. Both these superpassages have actually passed floods about twice as great as those for which they were designed.

Neither the remaining portion of the main line nor the branches presented any special difficulties other than those inseparable from the execution of a great irrigation work in a tract in which both the local labour and the local resources of all kinds were entirely inadequate, practically the whole of the 900 million cubic feet of excavation in the main line being removed in baskets on the heads of men and women, without the use of mechanical appliances of any sort. The canal was opened for irrigation in 1882, although several of the branches were then unfinished and the construction of the distributary system had hardly been begun.

The mileage of the channels of the Sirhind Canal System, 3,733 miles, is only exceeded by those of the two Ganges Canals which have 3,861 and 3,796 miles

respectively. The Sirhind Canal irrigates 1,600,000 acres, of which 1,050,000 acres are on the British and 550,000 acres on the Indian State branches. Its total capital cost up to date is £4 million; the British share is £ $2\frac{1}{2}$ million, on which a return of about 12 per cent. is realized.

The opening of the Ganges Canal had shown that there were certain defects in its design, and in 1866 a Committee was appointed by Government to decide as to the remodelling necessary and also as to the possibility of increasing the irrigated area in the Ganges-Jumna watershed by means of a second canal from the Ganges with its head further down the river. The result of the enquiry showed that it was quite feasible to construct such a canal by making a weir across the Ganges in the neighbourhood of Rajghat, but the Committee suggested that it might be wise to postpone consideration of the project until the value of water for irrigation had risen. The failure of the rains in 1866 demonstrated, however, that the protection of the tract was a matter of urgency, and in 1868 the preparation of a detailed scheme was undertaken. The project was actually sanctioned in 1872 and work commenced in that year, but during construction its scope was considerably modified and it was not until 1879 that sanction was communicated to the revised scheme as actually built.

The system comprises a weir across the Ganges at Narora, some four miles below Rajghat, and a main canal taking off from the right bank of the river. This canal is 62 miles long. Two large branches, the Farrukhabad and Bewar branches, are thrown off at the 26th and 40th miles respectively, and in the 56th mile, at Gopalpur, the junction with the Ganges Canal (which, since the construction of the Lower Ganges Canal, is usually known as the Upper Ganges Canal) is effected. At this point the Lower Canal crosses the old Cawnpore terminal line of the Upper Canal, the latter flowing into it on one side and continuing, considerably enlarged, on the other. The main canal terminates at mile 62 in two great branches, the Etawah and Bhognipur branches, the former

of which is the original Etawah terminal line of the Upper Canal which is here intersected by the Lower Canal and is now fed entirely by the latter below the junction.

The most interesting work on the system is the aqueduct over the Kali Nadi, and the failure of the original work, seven years after its completion, seriously retarded the development of irrigation from the canal. It had been given a waterway of five spans, each of 35 feet, the dimensions being fixed only after considerable deliberation, as it was recognized that much of the data essential to a positive determination of the flood discharge of the nadi was lacking. No actual flood measurements were available but local enquiry and the results of an investigation based upon the flood levels recorded on two neighbouring bridges, a railway bridge and a road bridge a century old, seemed to indicate 18,000 cubic feet a second as a liberal allowance, a depth of not more than 13 feet being anticipated. The work was finished on these dimensions in 1878, and stood for six years, though in 1880 for a short time a flood of 16 feet occurred.

In 1884 a flood of 22 feet came down, the discharge amounting to over 40,000 cubic feet a second and, being headed up 3½ feet by the aqueduct, tore away one-fourth of it. The fact that the earlier bridge levels could not be relied upon was demonstrated by the carrying away of their approaches, so that a great portion of the stream went round them at both ends. It was evident that the old work, even if restored, was insufficient in discharge capacity, so an estimate for a new one, capable of carrying the 1884 flood, was prepared, and meanwhile the injured one-fourth was temporarily replaced. Fortunately nothing permanent had been done when, in July 1885, the river rose again, this time running a mile wide and carrying nearly 140,000 cubic feet a second, a flood due to a cyclonic storm which gave a rainfall of 20 inches in twenty-four hours over a thousand square miles of the catchment of the nadi, denuded of vegetation by the summer heat. The aqueduct headed up the water 13 feet and under the tremendous pressures engendered the whole structure was torn asunder. Nothing

but a portion of two of the wings suspended above the flood remained to show where the work had once been. Every road and railway bridge on the lower 150 miles of the river's course, including the two bridges which had been utilized for the calculation of the probable discharge, were likewise swept away and engulfed.

The aqueduct over the Kali Nadi which was built to replace that destroyed is one of the finest works in India and is probably the largest of its kind in the world. It has fifteen arches each of 60 feet span with a width of 149 feet. The abutments and piers are based upon 268 wells sunk over 50 feet below the river bed, the total sinking amounting to nearly three miles. Four thousand work-people were engaged upon it day and night for four years, over a million cubic feet of concrete and 4¾ million cubic feet of brickwork being utilized in the structure. The waterway now provided for the nadi is sufficient to meet any possible future flood emergency. The canal was re-opened at the latter end of 1889, the aqueduct being finished within four days of the date fixed for its completion four years before.

The Lower Ganges System comprises 662 miles of main canal and branches and 3,134 miles of distributaries. It irrigated over a million acres in 1919-20 and returned nearly 7½ per cent. on a capital outlay of over £4 million.

The Agra Canal is a smaller work, also in the United Provinces, which calls for no particular mention.

The Swat River Canal, or as it is now more usually called, the Lower Swat Canal, is situated in the North-West Frontier Province beyond Peshawar, in the Yusafzai Valley, at the extreme limit of British India. The construction of this canal was prompted mainly by political motives, in the hope that the existence of such a work would tend to pacify and settle the border. If only members of the Mohmand and other tribes from beyond the frontier could be induced, by the promise of good crops, to settle peaceably in British territory a great step

forward would, it was felt, have been made in the direction of promoting habits of industry and friendly intercourse among the border clans.

A more forbidding country in every respect than that in which the operations had to be carried on would be difficult to picture. The average rainfall was only 14 inches, and liable to fall to half this amount in a year of drought. It was barren, treeless and almost uninhabited, while about it lay an inhospitable land peopled mainly by predatory marauders. Military guards had to be employed for the protection of all working parties, and every engineer's bungalow was a fort from which none ventured after dark and which every night was guarded by sentries. Soon after work commenced it became evident that the cost had been underestimated. Opposition was experienced from the tribes immediately beyond the frontier, who early in the proceedings made a raid upon the labourers employed on the channel excavation and killed several of them, while the people within the British borders were also for a long time either openly or passively hostile. These circumstances naturally not only increased the difficulty of obtaining labourers or contractors at anything like ordinary rates but also necessitated considerable expenditure in order to assure protection and confidence. The demand for labour for the maintenance of the lines of communication with Afghanistan during the war of 1878-80 tended still further to increase the rates, as did also the fact that the country was almost devoid of fuel, which could only be procured from beyond the border at an exorbitant price, the cost of bricks and lime being greatly enhanced thereby.

Consequently in 1880 a revised estimate, amounting to more than double the original one, was prepared and submitted. It received the sanction of the Secretary of State in the following year, but, as there seemed little likelihood of the work proving remunerative, it was removed from the category of productive works. The system was eventually completed in 1885.

The canal has its head on the Swat River, about two miles above the Abazai Fort, where it debouches from the hills. No weir was required, advantage being taken of a reef of rock which runs across the river immediately below the head regulator, which proved sufficiently high to obviate the necessity for artificially raising the water level. From its head the canal, which has a capacity of 700 cubic feet a second, runs eastwards at the foot of the rising ground and terminates at its twenty-first mile in two large distributaries, one of which is practically a continuation of the main canal. This distributary, turning southwards, was the easternmost channel of the system as originally constructed, and ends, after a course of seventeen miles, six miles beyond the cantonment of Hoti Mardan.

If the original estimate of cost was far too low, at least the estimates of the revenue obtainable from the work were equally so. It was anticipated that by 1888, three years after the opening of the canal, 24,000 acres would be taking irrigation, but so popular did the scheme become when once its advantages were perceived that no less than 108,000 acres, or 18,000 acres more than was forecasted as the ultimate area likely to be served, were irrigated in that year. So satisfactory indeed were the results that the project was restored to the productive class. In 1919-20 it irrigated 162,000 acres and yielded a return of 9½ per cent. on a capital outlay of £450,000.

Not only has the system been eminently successful financially, but politically also it has achieved all and more than all that was hoped from it. This may be seen by comparing the country in 1875, when the surveys were in progress, with the same tract as it appeared only twenty years later, that is to say ten years after the opening of the canal. In 1875 it was a barren wilderness, uninhabited and almost uninhabitable ; by 1895 it was a wide expanse of cultivation, dotted with villages occupied by a law-abiding and contented peasantry. In 1875 there was not a tree to be seen ; by 1895 avenues of trees had sprung up along the canal and its distributaries. In 1875 no officer was permitted to go outside cantonments without

being armed and accompanied by an armed escort ; by 1895 nothing of this sort was required and the tract was as peaceful and secure as any in the Punjab. Even the most optimistic hopes originally entertained of the project fell far short of the results actually achieved.

The construction of the Mutha Canals Project in the Bombay Presidency marks yet another stage in the history of irrigation in India. India was already well ahead of other countries both in the size of her canals and in the magnitude of the river works from which their supplies were drawn ; with the construction of the Mutha project she entered upon a new field, the building of great masonry dams.

At the time when the work was proposed, the construction of high masonry dams was new not only to Indian but also to English engineers. Such dams had, however, been successfully built in France, Italy and Spain, and it was only after an exhaustive study of the principal examples in those countries that the project for the Mutha reservoir was put forward. The object of the scheme was twofold, the protection from famine of a very precarious tract in the Poona District and the assurance of a supply of potable water to the town of Poona and to the cantonments at that place and at Kirkee.

The great want of water in the station of Poona had led to the construction, some twenty years before the present project was proposed in 1868, of the so-called Jamsetjee Bund or weir on the Mutha River which passes through the town, the object of which was the formation of a pool in the bed of the stream from which water could be drawn. Unfortunately, however, owing to the lack of a suitable site above the city, the weir was built below it, with the result that the main sewer discharged into the stream above the weir and most of the sewage matter was retained in the pool. A cesspit, which was to be cleared daily, was then constructed to receive the contents of the sewer, but the remedy was almost worse than the

disease as not only was the daily clearance extremely expensive but the cesspit itself, as might have been foreseen, proved a public nuisance to the neighbourhood. Moreover, the purity of the water supply was not appreciably enhanced as not only did the cesspit overflow into the river every time there was a sudden storm but by no means all the sewage of the town found its way to the sewer and great quantities of foul matter, which accumulated in the city itself and on the banks of the river, continued to be washed into the stream above the weir with every fall of rain. Poona, excluding the cantonments, had at that time 90,000 inhabitants and was also the principal station of the Bombay Army, and it is hardly to be wondered at that the Government of the presidency were prepared to welcome any measures, however heroic, which gave promise of ameliorating conditions in the city.

Colonel Fife of the Royal Engineers was the originator of the scheme. He proposed a dam across the Mutha at Khadakwasla, about ten miles above Poona, and two canals, one on the left bank of the river to carry a supply to Kirkee, also an important cantonment, and one on the right bank to bring water to Poona and to irrigate the country beyond. The work of construction was commenced in 1869 and was completed ten years later.

The dam and waste weir, which are together just short of a mile in length, stretch across a deep valley, the dam being 99 feet high above the river bed and 107 feet high above foundation level at its highest point. It is built of uncoursed rubble masonry, a type of construction which, advocated by Colonel Fife, was only adopted after some discussion among the experts who examined the design; experience has, however, proved the soundness of Colonel Fife's proposal and uncoursed rubble is now being used in the far higher dams under construction in other parts of the Deccan. Of the two canals which draw their supplies from the reservoir the Left Bank Canal is only a small channel, carrying 38 cubic feet a second, and terminates, after a course of 18 miles, just beyond Kirkee. The Right Bank Canal is 70 miles long and carries about 400 cubic feet

a second; after passing Poona it proceeds eastwards and irrigates a very precarious stretch of country in the district of that name. Towards the tail a large tank, the Matoba Tank, collects and distributes the surplus water of the canal.

The work is one of great value, far more so than the direct returns from it indicate. The necessity for affording a supply of good water to Poona would alone have been a sufficient justification for the project and added to this a tract extremely liable to famine is efficiently protected. Although classed as unremunerative, the project has proved a thoroughly sound investment on the part of Government.

In addition to these larger works, the facilities for obtaining funds due to the introduction of the loan system led to the construction of new schemes in several provinces. In particular, in Madras, the scope for projects dependent wholly upon the natural supplies available in the rivers being exhausted, storage schemes began to be constructed; and considerable further progress was made in the extension and improvement of the old inundation canals in Sind. It is to this epoch that the Desert Canal belongs which, running just south of the border between Baluchistan and Sind, has been an important factor in weaning the frontier tribes from their inveterate habits of lawlessness and rapine.

CHAPTER VI

The Early Punjab Colony Canals

In its strict etymological sense the Punjab, or Land of the Five Rivers, is the country enclosed and watered by the Jhelum, Chenab, Ravi, Beas and Sutlej, though the province, as at present constituted, includes also the tableland of Sirhind, south of the Sutlej, and the so-called Sind-Sagar watershed, the wedge of country lying between the Jhelum and the Indus.

There is, with the single exception of Sind, no portion of India which is so favourably situated as regards its rivers or so unfavourably as regards its rainfall as the Punjab proper, that is to say, the tract between the Jhelum and the Sutlej. By far the greater portion of it has less than fifteen inches a year and much of it less than ten; when it is remembered that even these small amounts are liable to serious deficiency in a year of drought, it will be readily comprehended that, until the introduction of irrigation, practically the whole vast stretch of country was desert waste. The only exceptions were the fringes of the rivers where cultivation, though never very prosperous, was rendered possible to some extent at least by means of inundation canals and wells.

The problem which confronted the Punjab Government in this case was quite different to any which had previously had to be faced. In all other irrigation schemes, with the single exception of the Lower Swat Canal, the main object had been the improvement of existing cultivation; the cultivators had been in occupation long before the canals were even projected. But in the Punjab desert, or Crown Waste tracts as they are called, there was no resident population, beyond a few nomads who eked out a precarious existence as graziers, and consequently it was necessary, simultaneously with the introduction of irrigation, to transport bodily whole communities into the new areas thus opened up.

The process of colonization is so complicated and the terms offered to settlers in the various colonies have been so diverse that anya ttempt to deal fully with the subject would go far beyond the legitimate scope of this outline. The most that can be done is to give a brief account of the operations common to all colonization schemes.

Prior to the construction of the canal, and with a view to determining the approximate position of the main line and branches, the tract to be colonized is divided up into large squares or rectangles, each of which is subsequently subdivided into smaller similar squares or rectangles. The whole tract is, in this way, demarcated into equal and regular areas, the shape and size of which have varied in the several schemes, being 22½-acre squares in the Sidhnai colony, 27·8-acre squares in the Lower Sohag, Lower Chenab and Lower Jhelum colonies and 25-acre rectangles in the Triple Canal colonies. A square or rectangle is the usual unit of allotment, and each such unit is, for the purpose of the revenue assessments, again subdivided into still smaller squares or rectangles, each of about one acre in extent. In the Triple Canal colonies nearly four million such small rectangles have been demarcated.

In a colony tract the alignment of the watercourses precedes the creation of holdings and consequently it is possible to make the boundaries of each group of allotments coincide with the boundaries of the area commanded by the watercourse which irrigates it, the area commanded by one or more such watercourses being constituted into a village. Thus no two villages are ordinarily called upon to share a watercourse, to the risk of peace and order. The village boundaries having been settled, the general lay-out of the settlement is determined, the main streets are demarcated, and land is set aside in the vicinity for grazing grounds, for the accommodation of village servants and for communal purposes, such as tanks, tan-pits or manure heaps. All this is done before the colonists arrive ; they find the village sites ready for

them, and have only to build their houses and commence breaking up their land. The colony villages, thus methodically planned, possess marked sanitary advantages over the ordinary Indian homesteads.

The choice of colonists is left, in the main, to the revenue officers of the districts from which they are drawn. The object of colonization is twofold, to open up new areas and to relieve pressure upon the land in those parts of the province where the agricultural population has reached or is approaching the limit which the land available can support. It is from these congested districts that the colonists are chosen, only members of agricultural tribes who are either hereditary land-owners or occupancy tenants being ordinarily eligible for the so-called peasant grants under which the bulk of the land is allotted. Selection is usually made personally from each village by the district officer concerned, and is by no means an easy matter. From the mass of applicants the ineligible must be weeded out : dotards and mere boys put forward in the hope of securing an extra square for the family, those who have already sufficient holdings, those who have mortgaged a considerable share of their land, the physically and mentally unfit, the village loafers and the like. When this has been done there remains a band of men, all connected by common ties and, to a large extent, by common descent, all physically fit to take up life in a new country under considerable initial difficulties, all short of land, but solvent and with sufficient resources to start them. Groups of this nature are despatched to the colonies as units, each group being of about the size required to form the nucleus of a new village, and in this way they all start at the same time and bring with them, ready made, the elements which go to form a separate village community. The weaker ones can get help in the shape of loans, cattle and seed from those better off, and the village is therefore far more suited to face the hardships inevitable in the first months of immigration than it would be were it built up from isolated individuals, none of whom knew or trusted his neighbour and between whom there was no cohesion of any kind.

The terms upon which peasant grants are made vary somewhat in the different colonies. The average area allotted to each individual is generally from $1\frac{1}{2}$ to 2 squares, or about 40 to 50 acres, the land being held by the colonist on probation as a tenant-at-will for a certain number of years. In most of the earlier colonies inalienable occupancy rights in the holding were granted at the end of this period, either free of charge or on payment of a nominal sum, but a revised procedure has since been introduced under which occupancy rights are granted after a first term of years and, after a further term, tenants are given the option of purchasing alienable proprietary rights at a privileged price, payable in easy instalments. Sometimes, as a condition of the grant, the settler is required to render a specific service to Government such as by undertaking to maintain a suitable mare for the breeding of Army remounts or to supply labour for the repair and maintenance of the canals, when necessary.

There are many other forms of grant, designed to suit the special circumstances of the grantee or of the tract to be colonized. For example, grants larger than the ordinary peasant grant are made to hereditary landholders of more substance and of better social status than the ordinary cultivator, while still larger allotments are sometimes conferred on men of means willing to experiment in improved methods of cultivation and irrigation. Grants are also often made to those whose services to Government, civil or military, paid or honorary, have been especially deserving of reward. Small areas are moreover sold by auction from time to time, to test the value of the land in the open market.

Once the grantees are established in their new villages, development proceeds apace. The alignments of the necessary communications between village and village and between the villages and the boundary roads which run parallel to the canals have already been demarcated, and on these alignments village roads come into being. The increasing harvests demand increasing facilities for transport ; metalled roads and railways make their appear-

ance, and upon them towns and markets spring up. Viewing a typical colony tract, flourishing as but few parts of India flourish, it is almost impossible to believe that only a few years previously it may have been a barren, waterless, uninhabited desert.

The history of colonization in the Punjab began with two small experiments, the Lower Sohag and Para Canals from the Sutlej and the Sidhnai Canal from the Ravi. Neither of these schemes, which came into being in the late eighties, is of the first magnitude, but they are of importance in that they gave the necessary proof that colonization was not only possible but could be made enormously lucrative both to the cultivator and to Government. Both schemes produced prosperous colonies and it was largely the success which attended them which encouraged Government to embark on the first colony project of real magnitude, the Lower Chenab Canal.

The Lower Chenab Canal can claim, with considerable justification, to be the most extensive and successful irrigation system in India and probably in the world. In view of this fact it is difficult now to realize how inauspicious was its commencement, how at one time it seemed doomed to ignominious failure, and what vicissitudes it passed through before it attained its present status.

The watershed between the Chenab and Ravi Rivers was an ideal situation for an irrigation canal. The Chenab afforded a splendid and unfailing source of supply, and neither deep digging nor any special engineering difficulties had to be faced, so that a system, inexpensive in comparison with its scope, was possible. The watershed was large, the soil for the most part very fertile and the bulk of the land Government waste. The rainfall, moreover, was extremely deficient, so much so that, in the upper portion of the tract, cultivation of any sort was very precarious without irrigation, while more than half the area was desert. Seldom if ever has a combination of circumstances so favourable to the introduction of canal irrigation been met with in any project.

The first proposals for the irrigation of the tract were framed in 1875 and contemplated an enormous canal, with its head above Merala where the headworks of the recently constructed Upper Chenab Canal are now situated, and a distribution system embracing the whole of the Chenab-Ravi watershed. Though it possessed many defects in detail the project was a remarkably complete one, but it proved to be in advance of its time. With no experience of colonization the financial prospects of the scheme appeared to Government to be, to say the least of it, uncertain, and in the circumstances they not unnaturally hesitated to embark upon the large expenditure, estimated at £3½ million, entailed.

The consequence of this refusal of the original project was a swing of the pendulum in the direction of excessive timidity, and the next proposal, framed in 1882, was for a small inundation canal, the so-called Ramnagar Canal, with its head some 40 miles below Merala, to irrigate 144,000 acres at a cost of about £300,000. This project was sanctioned in 1884, and the canal was opened in 1887. It was a complete failure from the first; the estimate of its cost was greatly exceeded and the prospects of its ever proving remunerative were extremely remote. It silted heavily in the flood season, and as the river fell there were no means of forcing water into it to mature the crops sown. In view of the uncertainty of the supply, colonization was an obvious impossibility.

In 1889, therefore, a fresh project was prepared, which provided for a weir across the river and a considerable extension of the canal system, the estimate amounting to £1 million and the anticipated area of irrigation to 400,000 acres. The site chosen for the headworks was some eight miles above the offtake of the Ramnagar Canal, this point being selected so as to enable the latter to be fed without any great modification of levels. The project was sanctioned in 1890, and construction was immediately commenced, a special circle of superintendence being formed for the purpose with Major S. L. Jacob in charge.

It is to the initiative of this officer that the Lower Chenab Canal, as it exists at present, is mainly due, for no sooner had he assumed charge of the works than he perceived the desirability of a further extension of the scope of the sanctioned scheme, and commenced to press upon the notice of Government the advisability of the preparation of a complete survey of the watershed with a view to the formulation of yet a third project, to embrace the whole area which could be commanded. His views were accepted and the necessary surveys were put in hand simultaneously with the construction of the weir. The difficulties attendant on these surveys, carried out as they were in uninhabited desert, were enormous, but eventually the whole watershed was cross-sectioned at 2,000 feet intervals and the maps so prepared have since been proved to be very fairly accurate. On the basis of them a revised project was drawn up in 1891 ; Major Jacob estimated for a canal with a head capacity of 9,000 cubic feet a second and included in the area to be irrigated all the land in the watershed where the sub-soil water level was more than 40 feet from the surface. The cost of these proposals was estimated at £2¾ million and the annual area of irrigation at 1,170,000 acres. This estimate was, however, modified by the higher authorities, the discharge being reduced to 8,000 cubic feet a second, the cost to £2¾ million and the annual area to 1,100,000 acres ; in this form the scheme was finally sanctioned in 1892. It may be stated at once that not only has the irrigated area been far in excess of this modified estimate but that it has actually reached a figure more than double that adopted in Major Jacob's more sanguine forecast.

The tract which the canal was designed to serve was one of extreme desolation. Water lay for the most part from eighty to a hundred and twenty feet below the surface of the soil, while the rainfall was scanty and uncertain. With the exception of snakes and lizards the country was extraordinarily devoid of animal life ; the vegetation, such as it was, consisted mainly of dusty shrubs, some of a certain value as fuel but others of no use either to man or beast, and grazing was, generally speaking, conspicuous

by its absence. The only inhabitants of the country were the indigenous nomads, a spare and hardy race who eked out a precarious existence by means of their camels and goats, being almost independent of any form of diet other than milk. Such was the country in which the engineers were destined to live and labour for many years, and which the Lower Chenab Canal has converted from a wilderness into a garden.

The canal carries the enormous discharge of 10,700 cubic feet a second, six times that of the Thames at Teddington, which it distributes by means of a system comprising 427 miles of main canal and branches and 2,243 miles of distributaries. There are nine branches, ranging from the great Gugera branch, with a discharge of 4,500 cubic feet a second, itself a large canal, to the little Kot Nikka with a discharge of only 360 cubic feet a second.

The canal has no engineering works of extraordinary character calling for special remarks, but its construction was complicated by the fact that the smaller canal and the new headworks had been opened in 1892, so that the enlargement of the main line from a width of 109 feet to one of 250 feet, including the rebuilding of the bridges and the regrading of the bed, had to be carried out while the canal was in flow and irrigation in course of development. The enlargement was effected by constructing a second channel alongside the first, leaving only an earthen embankment between, and subsequently both were run together. The removal of this embankment presented serious difficulty, as the tract commanded was almost waterless and the people were dependent on the canal not only for their crops but also for water for drinking purposes and all domestic needs; closures were therefore rarely possible and then only for very short periods. The excavation of the parallel channel was practically completed by the end of the cold weather of 1896-97, and between then and 1899 attempts were made to remove the dividing bank by means of powerful dredgers, with the canal flowing, but this method proved unsuccessful since, as the section of the bank was reduced, it breached irregularly, causing large silt deposits in some places and deep scour in others. Mean-

while, owing to the rapid development of irrigation, the necessity for admitting increased supplies into the canal, which was impossible so long as the obstruction remained, was growing more and more pressing, and eventually it was decided to remove the bank, which contained over 30 million cubic feet of earth, by spade and basket labour. The canal was closed for twenty days in 1899 and again for ten days in the succeeding April. Special arrangements were made for labour, and men were crowded on the bank as close as they could work. Large gangs were raised in the colonies of the tract, which rendered cheerful and material assistance. The action taken was completely successful, and at the end of the second closure the main line was clear.

Colonization began in 1892, and the colonists in the earlier years had an even harder time than usual. There was no railway to the colony, and they had consequently to march there through a country nearly as waste as that to which they were going, inhabited by tribes which showed little mercy to immigrants whom they could way-lay. Many, therefore, never reached the colony at all. Those who did found the tract peopled by nomads who neither desired nor expected the canal to be a success and who were determined to do all in their power to prevent its being so. The rainfall in the previous years had been very scanty and the country presented a particularly desolate appearance, so much so that many of the colonists refused to believe that the land was worth cultivating and returned to their homes. A serious epidemic of cholera broke out, and though those who survived and had the pluck to persevere were rewarded by an excellent crop, their troubles were not yet at an end, as the labour available was insufficient to harvest it all and, even when harvested, there was still the difficulty of disposing of the produce which had to go by the same perilous way by which the settlers came. The opposition offered by the nomads of the tract was also a constant source of trouble, and perpetual attacks were made by them on the colonists who were, for some time, unable to ward them off.

This was, however, only a transitory phase. Once the fertility of the virgin soil of the watershed had been

demonstrated there was no lack of fresh settlers, and the news of the magnificent crops which had converted the poorest colonists into men of substance in a couple of harvests spread quickly over the province. A land hunger arose which could not easily be appeased and it became possible to pick and choose the most desirable settlers from amongst the thousands who applied. The nomads soon found the colonists more than their match ; a railway for the carriage of produce was commenced in 1895, roads came rapidly into being, and towns and manufactories began to spring up in the former desert. In ten years the population of the tract had risen from 8,000 to 800,000. Lyallpur, the capital of the colony, is now an important city with an enormous export trade. In 1919-20 the value of the crops grown on the land irrigated by the Lower Chenab Canal was no less than £16 million, or nearly five times the capital cost of the work, practically the whole of these crops being raised upon land which, thirty years ago, was barren waste where hardly a blade of grass would grow.

The successful settlement of the nomads of the tract deserves special mention. Their criminal ardour having being cooled by vigorous repressive measures, their disinclination to take land was gradually overcome. The belief that the canal had come to stay began to force itself upon them and they found it advisable at last to make for themselves the best terms they could. They were treated with great liberality in the matter of grants and have long since settled down to a peaceful agricultural life ; having acquired much knowledge from the colonists most of them are now fair, and many of them decidedly good cultivators.

The capital account of the Lower Chenab Canal stands at £3¼ million, on which it yields an annual return of about 45 per cent. It is by far the most remunerative of the larger canals of India, and its revenue account shows an accumulated profit, after paying all interest charges and working expenses, of the enormous sum of £16½ million, which increases annually by about £1½ million.

As has already been stated, the subject of colonization is far too large and complex to be dealt with, otherwise than in outline, in a brief history of this nature, but enough has been said to show how pre-eminently successful the operations have been. Some idea of the esteem in which colony land is now held may be obtained from the results of the public auctions of small blocks of such land which take place from time to time. The first auction so held was in the Lower Chenab colony in 1892; an average price of £4 per acre was obtained which was regarded at the time as highly satisfactory. The latest auction was held in 1919, when about 3,500 acres of waste land in the new Lower Bari Doab colony came under the hammer; an average price of £59 per acre was realized and a maximum of £110 per acre. The flourishing condition of the people can also be gauged from the fact that, in the latter colony, the price obtained for shop sites in the market towns has averaged nearly £4,000 per acre. These figures are a clear index of the immense value to the cultivators of the grants made; in view of them the present rate of land revenue assessment in the Lower Bari Doab colony, namely, four shillings per matured acre, appears extraordinarily lenient. From the points of view of all concerned the colony canals have effected their purpose; they have proved a most remunerative investment to Government, have greatly relieved the excessive pressure of the population in the congested districts of the Punjab, have enriched the cultivators, have enhanced the general wealth of the country and have added several thousands of square miles to the agricultural area of India.

CHAPTER VII

THE EARLY PROTECTIVE WORKS

THE accord of sanction to the estimate of the Betwa Canal in 1881 marked the opening of yet another and a very important era in the history of irrigation works in India, namely, the era of protective works, that is to say, works designed primarily for the protection of precarious areas against famine, the direct returns obtainable from them being a secondary consideration.

The policy which at present governs the construction of such works was laid down by the Indian Irrigation Commission of 1901-03. A severe famine invariably imposes a heavy strain on the resources of the State. Government has always recognized its obligation to meet whatever expenditure may be necessary to save life at such times and, in addition, considerable losses are incurred in the shape of remissions of land revenue, the non-recovery of advances made to cultivators for the replenishment of seed or cattle, and the falling-off in the general revenues, under such heads as railways, excise, customs, salt and stamps, due to the impoverishment of the country-side. This falling-off may, after a serious famine, continue for several years. To avert these losses a considerable capital outlay is justifiable, and, apart from the financial aspect of the case, it is undoubtedly incumbent upon Government to take such precautionary measures as may be economically possible with the object of saving the inhabitants of insecure tracts from the loss and misery which famine imposes upon them.

There must, however, of necessity be a limit to the expenditure which Government can incur on the protection of precarious areas, and it was this limit which the Irrigation Commission were called upon to define. In accordance with their recommendations the system now adopted is as follows. First of all, the additional area which must be brought under irrigation in order to protect the district to the extent necessary to prevent any charges for famine relief in future is determined; this depends upon the population, the area which must be

protected per head of population (usually from a third of to half an acre), and the area already protected. If the capitalized value of the average annual expenditure on famine relief is divided by this area, the resulting figure is the amount per acre which can be expended on protection without imposing any further burden on the taxpayer than would be imposed upon him were the course of famine allowed to proceed unchecked. This amount is designated the "direct protective value of an irrigated acre."

The expenditure which may be justifiably incurred by the State on the protection of precarious tracts cannot, however, be limited to the saving which can thereby be effected in the direct cost of famine relief. The various sources of indirect loss already noticed, most of which can be obviated by the protection, must be taken into consideration and due weight given to the fact that the introduction of irrigation not only increases the general wealth and prosperity of the tract, which is to the direct advantage of the State, but also affects considerable areas lying outside the boundaries of the project by increasing the humidity of the air, raising the spring level in wells and augmenting the percolation flow in streams. It is impossible to assign any quantitative, and still less any monetary value to these effects ; even more difficult is it to define to what extent, apart from these material reasons, Government should be prepared to spend public funds in order to prevent the horrors of famine. The Irrigation Commission considered that, in general, it would be permissible to spend up to a maximum of three times its direct protective value for each acre irrigated, to which may be added the capitalized value of the net revenue anticipated from each such acre in payment for the water provided. The sum of these items is the so-called "permissible capital outlay per acre" and, in the case of every protective work submitted for sanction, it has to be shown that this permissible outlay will not be exceeded.

The first protective work to be constructed in India was a canal from the Betwa River in the United Provinces.

This project was first mooted in 1855, but no definite proposals were put forward until, in 1868, a report was prepared which established the practicability of such a canal for the irrigation of the triangular area in the Jalaun District formed by the three rivers Jumna, Pahuj and Betwa. The sub-soil water throughout this tract is at immense depths, making the cost of well irrigation prohibitive, and consequently, at the approach of drought, the people were in the habit of emigrating for the time to more favoured quarters. There was, in such circumstances, less accumulation of capital and less ability to tide over seasons of difficulty, and, when drought and famine did come, the miseries of want and depopulation were experienced with an intensity and duration quite unknown in the more secure districts of the province. In such a tract the expenditure of public funds upon famine protection was clearly justifiable.

Although the project for the scheme was completed in 1874, two earlier estimates having in the meantime been drawn up but rejected, the novel features connected with its financial aspects necessitated so much correspondence that it did not finally receive sanction until 1881. The estimate amounted to £320,000 on which a return of 1·7 per cent. only was anticipated. The actual cost of the project, on its completion in 1893, amounted to nearly £420,000, many of the works being found, during construction, to have been underestimated.

The headworks of the canal are situated on the river Betwa, near Parichha, seventeen miles from Jhansi. The river at this point has a discharge of 815,000 cubic feet a second, and the works are of proportionate size and solidity. The weir extends across the rocky bed of the stream ; its length is 4,261 feet and its greatest height 60 feet. By this means a reservoir is formed in the channel of the river which impounds 2,470 million cubic feet of water.

The history of the Betwa Canal has been a very chequered one. Its construction was followed by a cycle of years of exceptionally good rainfall, and irrigation

developed extremely slowly. This cycle was, however, succeeded by a series of dry years, and a marked expansion took place; the principal branch had consequently to be remodelled so as to enable it to carry 600 cubic feet a second instead of the 350 for which it had originally been designed, thus permitting larger volumes to be utilized when available in the river. This remodelling effected a considerable improvement in the efficiency of the system, no less than 163,000 acres being irrigated in the famine year of 1905-06. But the great weakness of the canal lay in the general insufficiency of its cold weather supply, and in 1905 work was commenced on the construction of a supplementary reservoir at Dhukwan, 25 miles above Parichha, a dam 3,924 feet long and 57 feet high being built for the purpose.

The total cost of the system, which comprises 168 miles of main canal and branches and 573 miles of distributaries, now amounts to £830,000. Financially the canal is not a success; it does little more than pay its working expenses, the return on capital being less than one per cent. In a normal year it irrigates somewhat more than 100,000 acres. But its value as a protective work is undoubted; it has yet to experience the test of a really severe famine (the Dhukwan dam was not in operation during that of 1905-06), but in such circumstances it could almost certainly irrigate and mature over 200,000 acres of crops, sufficient to save the tract commanded. Of its kind, therefore, it is a sound investment. A proposal is now under consideration for the construction of yet a third reservoir on the river, above Dhukwan, to increase both the scope and efficiency of the system.

The acceptance of the policy that non-productive works might be constructed for protective purposes led to similar projects being commenced elsewhere in India. The Rushikulya Project, a somewhat complicated system of reservoirs, weirs and canals, situated in the Ganjam District of Madras, is one of these. The Nira Canal in Bombay, the most successful financially of all the protective works, also belongs to this epoch, as do the Gokak and Mhaswad Canals in the same province.

CHAPTER VIII

OTHER WORKS OF THE NINETEENTH CENTURY

THE early improvements to indigenous canals, the great classic schemes, the Punjab colony canals and the first productive and protective works have now been described. A brief account of two projects, carried out mainly between 1887 and 1900, will bring this history down to the end of the last century.

The main feature of the Periyar System is the diversion across the Indian peninsula into the Bay of Bengal of a large river which nature had ordained should flow into the Arabian Sea. To effect this it was necessary to construct a huge dam in an inaccessible gorge 3,000 feet above the sea, in the middle of almost impenetrable and malaria-ridden jungle, and to carry the river from the lake thus formed through a tunnel bored through the main watershed of the country. The difficulties which had to be surmounted, both engineering and those due to the climate and to the inaccessibility of the site, were probably greater than have been met with in any other irrigation work yet undertaken in India.

The Periyar has its source in unsurveyed country in the Western Ghauts in Travancore whence it flowed, through uninhabited jungle, westwards to the sea. While its water was thus running to waste the Madura District of Madras, lying to the east of the watershed, was in a continual state of famine. Almost every alternate season was one of scarcity, and an exceptionally dry year caused acute distress. The river Vaigai is the only drainage of importance in Madura and on its scanty and unreliable supplies practically the whole irrigation of the district depended.

The idea of making a cut through the watershed and thus diverting the Periyar into the Vaigai was first mooted in the early years of last century, but a few levels taken showed the country on the east to be more than a hundred feet higher than the water level in the Periyar and the project was consequently set aside as "decidedly chimerical and unworthy of any further regard." The subject was,

however, discussed in a desultory manner from time to time and in 1867 a preliminary project for the diversion was prepared. This project contemplated raising the Periyar water to the required level by means of an earthen dam 162 feet in height and carrying it through the watershed in an open cut 52 feet deep. These proposals, in reality, did little more than demonstrate the feasibility of the diversion and afford a basis for discussion, but as a result two fundamental points were decided: that the dam, if constructed, must be of masonry or concrete and that the correct method of diversion was by means of a tunnel. Before, however, anything definite had been approved, the great famine of 1876-77 intervened, diverting to itself all the funds and attention available, and no further action of a practical nature was taken during the ensuing six years. Eventually, in 1882, Major (afterwards Colonel) Pennycuick, whose name will always be associated with the scheme as its designer and builder, was placed on special duty to prepare a revised project and estimate, which was sanctioned in 1884. Owing, however, to financial pressure, work was not commenced until 1887.

The principal feature of the scheme is the dam. This is situated in a V-shaped gorge in the Western Ghauts; it is built of concrete with a thick masonry facing and is 173 feet high from river bed to crest excluding the parapets. Its length at foundation level is 200 feet and at top 1,241 feet.

It is a peculiarity of the Periyar dam that a large proportion of the water it impounds is unavailable for irrigation purposes, being required merely to raise the remainder to the level at which it can be delivered on the further side of the watershed. The level of the sluice through which the water is abstracted is only 48½ feet below the crest of the dam. Owing to the wedge-shaped formation of the valley the upper portion of the storage is, naturally, the more important; actually the lake holds, when full, 15,661 million cubic feet of water, of which 9,176 million cubic feet can be utilized as lying above the level of the sluice.

From the most northerly arm of the reservoir the water is led for a distance of rather over a mile through a deep open cutting to the mouth of the tunnel. This tunnel, which carries the required supply through the watershed, is nearly a mile and a quarter long, and is capable of carrying about 1,250 cubic feet a second, its discharge being controlled by a sluice at its entrance. On the further side a short open cut conveys the water into a natural ravine, by which it finds its way into the Vaigai.

The situation of the Periyar dam was such as to make its execution a matter of the utmost difficulty. The country was uninhabited and covered with dense jungle, and the nearest railway station was nearly 90 miles distant. The only line of communication in the vicinity was the road from Madura to Travancore which passed through a clearing in the jungle about eight miles from the dam site; its gradients, as it ascended the so-called Gudalur Ghaut to reach the summit of the watershed, were, however, too steep to admit of the economical transport of large quantities of materials along it. As the quarries were situated four miles from the foot of the Ghaut, up which the road wound for a further four miles, the question of the best form of transport was an all-important one. After several alternatives had been discussed and rejected, it was decided to erect a wire ropeway from the foot of the Ghaut to the summit at Tekadi, and to connect Tekadi with the work by canalizing a small natural stream which flowed into the Periyar about a mile above the dam, utilizing water transport in this reach.

The principal trouble connected with the actual construction of the dam was that of diverting the river while the lower portions of the work were in progress. At the dam site the deep channel lay from 12 to 20 feet below lowest water level and the narrowness of the gorge was such as to cramp operations and to render the diversion a matter of the utmost difficulty. The Periyar is, at best, an extremely refractory river. From June to November rain is practically continuous, falling on an average on four days out of five and, of course, keeping the water at a high level thereby,

while even during the remainder of the year sudden floods of from 10,000 to 120,000 cubic feet a second are constantly experienced. A description of the methods ultimately adopted for dealing with this water would involve a technical account altogether outside the scope of an outline of this nature. Mr. A. T. Mackenzie, in his admirable *History of the Periyar Project,* tells how the first earthen dams erected to effect the diversion were washed away by a sudden unseasonable flood ; how the design had to be completely altered at a moment's notice to prevent the waste of a whole season's work ; how night and day, until the completion of the scheme, as so altered, the partially finished embankments were patrolled and the cavities which were constantly forming hurriedly repaired ; how at last the great coffer dam in which the masonry was to be enclosed was completed and pumping commenced and how, on the following day, 3 inches of rain fell in four hours with the result that a flood swept down upon the work, breached the dam and buried pumps and pipes in the river bed. From September 1888 to January 1890 the struggle with the river lasted ; in the latter month the coffer dam was finally repaired and masonry commenced. The labour involved had been herculean, much of the work having to be done at night, and in water, at the low winter temperatures experienced, even in India, at an altitude of 3,000 feet above the sea, causing great suffering from exposure to all concerned. Indeed, as Mr. Mackenzie remarks, "Had it not been for the medicinal virtues of arrack, it is difficult to see how the Periyar dam would ever have been built." The dam was eventually completed to its full height in October 1895.

The vagaries of the river were by no means the only factor which delayed progress, the unhealthiness of the tract being an even more serious one. Malaria and its concomitant complaints played havoc with the labour throughout the whole period of construction. As the lake rose, things went from bad to worse, since the large area of vegetation submerged and rotted added to the disease. Both the lake and the navigable canal usually smelt abominably. The statistics for the worst month, June 1895,

show that the hospital attendance rose to the extraordinary figure of 1,465 attendances in the month per thousand labourers employed. During the whole of this year the average number of labourers was 2,449 and the average monthly hospital attendance 1,081. As many of the sick refused to attend hospital and either treated themselves in their lines or were removed to their homes by their relatives, even these figures give an inadequate idea of the extent to which disease was prevalent, in spite of every possible precaution being taken. The mortality was also very high, 123 deaths occurring in the camps in 1895. Officers and subordinates suffered similarly and there was not one who escaped the prevalent fever while many had to be transferred on that account.

In such circumstances, and considering the remoteness and general inhospitality of the tract, it is not to be wondered at that labour, both skilled and unskilled, was difficult to obtain, in spite of the high wages offered. Any man who could read and write and had the courage or was under the necessity to enter this unknown land could rely upon immediate promotion to foreman ; masons were almost impossible to procure and Mr. Mackenzie relates how "any ambitious cooly who could borrow or steal a pair of old boots and a trowel presented himself unblushingly for the job." The fact that the quality of the masonry in the Periyar dam is, generally speaking, first class is due almost entirely to the excellence of the materials and to the unceasing vigilance of the supervising staff, this result being attained in spite of, and not because of, the masons. Posts requiring skill of a higher order, such as mechanics, were even more difficult to fill and, as often as not, no sooner had a suitable incumbent been found than he had to be invalided.

It was in an atmosphere of continual anxiety regarding the river, the prevailing sickness and the supply of labour that the Periyar dam was built. Of the benefits conferred by its construction there can be no two opinions, as it has rendered one of the most precarious tracts in Madras practically free from want. Where formerly 66,000 acres were

irrigated from scanty and unreliable sources, 176,000 acres are now provided with an unfailing supply of water. In spite of the great cost of the scheme, £1 million, compared with the extent of new irrigation effected, it has proved a financial success. It pays 5½ per cent. on capital and is rapidly wiping off the heavy arrears of interest which accumulated during its construction and the early years of its operation.

The second scheme which requires a brief mention is the Jamrao Canal in Sind, which serves a great alluvial plain, about a hundred miles long with a maximum breadth of twenty-eight miles, lying between the Eastern Nara and the Indus in Sind. Prior to the construction of the Jamrao Canal less than ten per cent. of the 790,000 acres of culturable land included in this plain was actually cultivated, the remainder being desert waste.

The uncultivated waste of Sind, or "pat" as it is locally called, approaches much more nearly to the popular idea of a desert than do the desert areas in the Punjab. In the latter stunted bushes and clumps of dry grass vary the scene, while the country undulates to some extent at least ; whereas the "pat" of Sind stretches away dead level to the circle of the horizon, without so much as a shrub or a stone to break the monotony of the view. Given, however, sufficient water, the "pat" is extremely fertile and capable of bearing magnificent crops.

The headworks are situated at about the hundredth mile of the Eastern Nara, just south of the point where it emerges from the Khairpur State. They consist of a weir 1,250 feet long, 7 scouring sluices, and a head regulator. The main canal, which is 117 miles long and has a width at the head of 125 feet, flows for twelve miles through a region of sand-hills before emerging into the culturable plain. It has one large branch, 59 miles long, and feeds 493 miles of distributaries.

The construction of a work of this magnitude in an inhospitable desert, where water could only be obtained with the utmost difficulty, proved both arduous and

expensive and its completion within five years was only accomplished by the exercise of great energy on the part of the officers in charge. The cost of the system now stands at £900,000 ; it irrigates a quarter of a million acres and returns nearly 5 per cent. on capital. This modest return is largely due to the very low rates imposed in Sind, which bear little or no relation to the enormous enrichment of the countryside which has resulted from the construction of the work.

CHAPTER IX

PRODUCTIVE WORKS OF THE PRESENT CENTURY

THE opening of the present century was marked by a very important event in the history of irrigation in India, namely, the convening of the Indian Irrigation Commission. This Commission, consisting exclusively of irrigation and revenue experts, under the presidency of Colonel Sir Colin Scott Moncrieff, toured throughout the country in 1901 and 1902, and in 1903 presented a report which, in addition to recommending definite lines of policy regarding the selection, financing and maintenance of irrigation works, dealt also in detail with practically every scheme under consideration at the time. As a result of the Commission's recommendations a large number of new works were undertaken ; to such an extent has this been the case that the total capital expenditure on productive and protective works has been doubled since the beginning of the century, while the area irrigated by them has increased by over 70 per cent.

While the Commission was sitting and for a year or two thereafter there was, however, a period during which little new work was put in hand. Information had to be collected regarding the various schemes and, when the report was published, they had to be re-examined in the light of the recommendations made. The real acceleration of construction began in 1905-06, in which year an outlay of £ 1¼ million was incurred on productive and protective works, this being the first year in which over £ 1 million had been spent. By 1911-12 the annual expenditure had risen to £2,860,000 ; it remained at about £2¾ million for the two years following, after which the outbreak of war and the consequent demands upon the public purse made drastic reduction necessary.

The first work to claim attention is the great Triple Canals Project in the Punjab which is the largest irrigation work executed in India up to date and which constitutes a striking monument not only to the engineering

skill of those who were entrusted with its design and construction but also to the extraordinary far-sightedness of the two officers who, independently, put forward the original proposal for the scheme. Its main object is the irrigation of a tract of country lying between the Ravi and Sutlej Rivers, known as the Lower Bari Doab, and, since the whole of the winter volume of the Ravi was already hypothecated to the existing Upper Bari Doab Canal, the Sutlej naturally appeared the most suitable source of supply to the area in question. A scheme for a canal with its head at Harike on the Sutlej, immediately below the junction of that river and the Beas, was actually prepared and submitted for sanction ; it was, however, strongly opposed by two of the witnesses who gave evidence before the Irrigation Commission, Sir J. Wilson, Settlement Commissioner, Punjab, and Col. S. L. Jacob, of Chenab Canal fame, who had recently retired from the Public Works Department. The reasons underlying the opposition of these officers to the project were, firstly, that the supplies in the Jhelum were much greater than could be utilized in the watershed between the Jhelum and the Chenab, and that the irrigation of the Lower Bari Doab represented the last possibility of turning them to beneficial use and, secondly, that the Sutlej water would certainly be required in days to come for the further development and extension of irrigation on either side of the latter river. The Irrigation Commission were so impressed with these views that they issued an *ad interim* report, recommending that this aspect of the case should be thoroughly examined before the project for the canal from Harike was finally sanctioned ; the result of this examination was the preparation of the Triple Canals Project, by means of which the surplus water of the Jhelum is transferred into the Lower Bari Doab. The far-sightedness of the original instigators of the scheme on these lines has now borne fruit in that thereby the great Sutlej Valley Canals Project, which is described in Chapter XI, has also been rendered possible ; had the Sutlej water been taken into the Lower Bari Doab, development of irrigation in the Sutlej Valley would have been at an end. The names of these two officers will always be associated with the Triple Canals

Project, as will also that of Sir John Benton who carried out the investigations required, amplified and greatly improved upon the original proposals by providing for a large area of irrigation in the two watersheds between the Jhelum and the Ravi which had not previously been contemplated, and was responsible for the designs and estimates.

The transfer of the water was effected as follows :— A regulator was constructed at Mangla on the Jhelum at a point where the presence of a permanent shingle bar across the river rendered the provision of a weir unnecessary. From Mangla the Upper Jhelum Canal carries the Jhelum water into the Chenab, discharging it into the latter above the headworks of the Lower Chenab Canal at Khanki. The Lower Chenab Canal is thus fed with Jhelum water and the Chenab water so freed is taken, from new headworks situated at Merala, 36 miles above Khanki, into the Upper Chenab Canal, the second link of the Triple Canals. This canal runs southwards to the Ravi, which it crosses on the level at Balloki ; below Balloki it is known as the Lower Bari Doab Canal.

In so far as the surmounting of engineering difficulties is concerned the Upper Jhelum Canal must, of the three sections of the project, be given pride of place. The head regulator, which has to deal with a river having a difference of 51 feet between low water level and maximum flood surface, is a massive dam, rising 69 feet above the canal bed, and 96 feet above lowest foundation level. The canal has a bed width of 220 feet and for the first 1,500 feet of its course, through the so-called Mangla Cut, is in heavy digging, the maximum depth being 110 feet. It runs for 62 out of the 89 miles of its length along the slope of the Pabbi hills, passing in quick succession through deep cuttings and over high embankments and crossing the whole of the drainage of the range. In all, no less than sixty drainages cross the alignment, which are dealt with by level crossings, syphons, culverts or inlets as the circumstances of each dictated. Mere figures are apt to make but little impression, but two in connection with the Upper Jhelum

Canal are worth quoting. The quantity of earthwork executed amounted to over 1,300 million cubic feet, and 33½ million cubic feet of masonry and concrete were put into the works.

The Upper Chenab Canal is the largest perennial irrigation canal in the world. Its head is at Merala, where the Chenab is spanned by a weir 4,070 feet long. The canal has a bed width at the head of 240 feet and a full supply depth of 11·1 feet at which depth 11,700 cubic feet a second are carried.

The crossing of the Ravi by means of a level crossing has given rise to the largest work of its kind yet constructed. The Balloki Level Crossing comprises an inlet, combined with the tail fall of the Upper Chenab Canal, a barrage across the river, and the head regulator of the Lower Bari Doab Canal on the other side. The barrage is 1,647 feet long and consists of thirty-five bays each of 40 feet clear span, divided by piers 7½ feet wide. The work is designed to pass the flood discharge of the Ravi, computed at 150,000 cubic feet a second, with a freeboard of 5 feet.

The Lower Bari Doab Canal, which commences at the barrage, is 195 feet wide and carries a discharge of 6,750 cubic feet a second, the main line being 134 miles long.

The original estimate of the project was sanctioned in 1905 and operations commenced simultaneously on all the canals in that year. As was inevitable in the case of a work of this magnitude, an enormous amount of detailed investigation had to be undertaken before the final arrangements could be settled and means devised to meet the unexpected conditions which presented themselves. The work was, however, carried to completion at what, in all the circumstances of the case, was a most satisfactory speed. Each section of the scheme was opened as it was practically finished, the Upper Chenab Canal in 1912, the Lower Bari Doab Canal in 1913, and the Upper Jhelum Canal in 1915. The whole work was not, however, fully completed until 1917. It now consists of 433 miles of main canals and branches and 3,010

miles of distributaries, in connection with the distribution of water from which nearly 20,000 miles of watercourses have also been constructed.

The total area commanded by the project is 3,997,000 acres or 6,250 square miles and it is proposed that 1,675,000 acres shall be irrigated annually. There is no fear of these results not being realized, since already, in 1919-20, 1,711,000 acres were irrigated by the project. The Triple Canals scheme has also brought a further huge extent of waste land under cultivation, 1,570,000 acres of the area commanded being classed as Crown Waste. Of this area 1,490,000 acres were available for allotment. Colonization has been going steadily forward and, up to the end of September 1920, 880,000 acres had already been allotted, including areas reserved for horse breeding and other purposes. The areas available on the two upper canals have been allotted almost in full, most of the unallotted balance being in the Lower Bari Doab colony. A considerable proportion of this unallotted balance is reserved for soldier grantees and, pending their arrival, has been let out for what is known as "temporary cultivation," a temporary tenant being permitted to cultivate the land until it is finally allotted; 442,000 acres were so leased in the Lower Bari Doab colony in 1920, being over 70 per cent. of the unallotted land.

The total cost of the project is now estimated at £10½ million, including the cost of certain improvements still remaining to be carried out, and an eventual return of nearly 8 per cent. on capital is anticipated. This, however, is merely that portion of the return which will accrue to the State in a measurable and direct form, and in no way represents the vast indirect benefits which will result from the scheme. The value of the crops which were raised on land irrigated by the system in 1919-20 was estimated at no less than £9⅓ million, the bulk of which is a new accretion to the wealth of the province, and nearly 2,500 square miles of waste land is, for the first time, now being brought under the plough.

Another great project in the Punjab is the Lower Jhelum Canal. This canal irrigates the western portion of the watershed lying between the Jhelum and the Chenab Rivers in the Punjab, known locally as the Jech Bar, an almost rainless tract with a deep spring level, cultivation in which was practically impossible without artificial irrigation. Prior to the advent of the canal, the country was covered with a low scrub jungle, sometimes dense and elsewhere scattered and thin. Here and there were small patches of indifferent dry cultivation in local hollows where rainfall water was expected to collect ; but the chief occupations of the scanty population which inhabited the tract were limited to cattle grazing and cattle lifting. The soil was, however, known to be as a rule exceedingly fertile, needing only a regular supply of water to render the labour of cultivation extremely remunerative.

The main canal has a bed width at the head of 140 feet, the full discharge capacity being 4,100 cubic feet a second, and a length of 39 miles, after which it bifurcates into the Northern and Southern branches, with a combined length of 208 miles. Nine hundred and ninety-six miles of distributaries have been constructed and about 7,600 miles of cultivators' watercourses.

The canal commands a gross area of about 1½ million acres of which 1,160,000 acres are designated as culturable. Of this total, 568,000 acres were Crown Waste. Colonization began in 1902, and the opportunity was taken to assist the Remount Department by attaching horse-breeding conditions to the majority of the grants. Generally speaking, these conditions require the tenant to maintain a mare suitable for breeding Army Remounts and give Government the option of purchasing the progeny prior to its attaining the age of 18 months at a reasonable price, £20 per head being the average paid in 1919-20. Up to date 439,000 acres out of an allotable area of 506,000 acres have been allotted; about 240,000 acres of this are either horse-breeding grants or have been made over direct either to the Army Remount Department or for regimental stud farms. The whole colony is an extremely prosperous one and Sargodha the capital, is now a large and flourishing town.

The ultimate cost of the canal is estimated at £1,800,000, 810,000 acres are to be irrigated annually and a return of over 19 per cent. on the capital outlay is anticipated. The work has already more than fulfilled these expectations. In 1919-20, 819,000 acres were irrigated and a return of 19⅓ per cent. was realized. Even these figures will probably be improved upon when certain channels, which do not at present command as much area as they might, have been remodelled so as further to elevate their water surface levels above the surrounding country.

Although only of moderate size, there are few irrigation works in India which make so direct an appeal to the imagination as does the Upper Swat Canal. With its headworks and upper reach situated across the frontier, in tribal territory, the political difficulties involved in it were even more formidable than the physical obstacles which had to be overcome.

Construction of the work commenced in 1907 and for a considerable period was carried on in the face of serious difficulty. The canal leaves the Swat Valley by means of a tunnel through the Malakand range of hills and, whereas the tribesmen living to the south of the range were strongly in favour of the scheme, in view of the improvement in their lands which was to be anticipated from it, those to the north, who had little or nothing to gain, were opposed to its construction as threatening their independence. In the circumstances it was but natural that they should attempt, if the inevitable was to be accepted, to make as much out of it as possible. Inferior workers themselves, they resented the work being given direct to imported labour or to the location of such labour in the vicinity of their villages, though they were by no meaus averse to taking lucrative contracts themselves and sub-letting them, at lower rates, to the same labourers. The work was regarded with suspicion, and considerable tension was caused by the fact that the project alignment crossed, for a short distance, an old graveyard which extended right across the Amandara Pass, through which the canal was to be excavated, and far up the hills on either side.

There was, of course, no intention of desecrating the graveyard, but it had been hoped that the tribesmen would consent to the removal of the graves to new tombs erected at Government expense. Apprehension as to the effect of the canal upon their tribal watercourses and cultivation, added to the wave of unrest which passed over the frontier in 1908 in consequence of the Mohmand Expedition, complicated the position, and in 1909 the abandonment of the project was seriously mooted.

By means, however, of unremitting zeal and diplomacy on the part of all concerned the situation was saved. The location of the headworks was changed (it may be remarked, as illustrating the nature of the tract, that one of the main reasons for the choice of the original site was the fact that it was within decisive rifle range of the Chakdara Fort), and a lower site adopted from which the canal could be aligned without disturbing either graveyards or cultivation. Local labour was employed to the greatest possible extent, quarrying royalties were paid and very liberal rates were given for the land required for the canal, this being in many cases taken on a perpetual lease instead of, as usual, being acquired outright, so as not to affect the position held in their villages by the owners as landlords. A large force of irregular armed police was recruited from among the tribesmen, thus affording occupation for a considerable number of them, and to this force was entrusted, with complete success, the safety both of the working parties and of the stores and plant utilized on the work.

The headworks are situated on the Swat River at Amandara, three miles below the Chakdara Fort. The canal runs through the Swat Valley for four miles, at which point it enters the tunnel by which it passes through the Malakand. This tunnel, which is two miles and one furlong in length, is by far the longest irrigation tunnel in India and but little shorter than the Khojak railway tunnel in Baluchistan, the longest railway tunnel in the country. Eighteen feet wide with a maximum height of 13½ feet, pierced through very tough muscovite granite,

from portal to portal it took 3½ years of labour to complete. A special hydro-electric plant was installed in connection with the work. A power-house was built about a mile and a quarter from the north portal of the tunnel and the water was supplied by a small canal taking out from the Swat River two miles higher up the valley, an effective head of 30 feet being obtained. After leaving the tunnel the supply passes down the Dargai Nullah and thence into a flume, pitched throughout with stone with a bed slope of 21 feet per mile, which it descends with a velocity of nearly 10 feet a second, culminating in a drop of ten feet about a furlong above the Dargai regulator. Altogether a fall of over 300 feet is negotiated in these five miles, frequent low vertical falls being provided throughout the length of the flume. At Dargai the canal bifurcates into two branches, hugging respectively the eastern and western slopes of the hills. The whole system comprises 144 miles of main canal and branches and 306 miles of distributaries.

Aligned as this canal has been along the spurs and slopes of hills cut up by ravines and torrents, there have been many engineering difficulties to be overcome. In addition to the great tunnel already mentioned, known as the Benton Tunnel after the name of its designer, there are seven other tunnels of an aggregate length of one mile, while no less than 167 drainage and torrent crossings have had to be provided. The project is certainly entitled, from the purely engineering point of view, to rank among the boldest yet constructed in India.

The estimated cost of the complete project is £2¼ million and the area to be irrigated annually is 315,000 acres. Although sanctioned as a productive work it is doubtful whether it will ever prove directly remunerative. But even should this be the case in respect of direct returns, it will ensure the advantages of a large increase in the food supplies of the frontier and the settling down to peaceful agriculture of a restless and turbulent people, forw hich results the price paid cannot be regarded as excessive.

There are one or two other productive works which have come into being during the last twenty years and which require a brief mention. The first years of the century saw the commencement of irrigation by major works in Burma. Taken as a whole, Burma has an ample, indeed in some parts an excessive, rainfall, but there exists in Upper Burma a so-called "dry zone" extending from Minbu and Magwe in the south to Shwebo in the north, a tract from which the Arakan hills divert the rainfall, which varies locally from 15 to 30 inches and is subject to great annual fluctuations. In many places this local rain affords the only source of irrigation and when it fails and there is no hope of securing a crop, considerable migration into Lower Burma takes place. It is within this dry zone that the three completed productive works, the Mandalay, Shwebo and Mon Canals, all of which have been completed since 1900, and the one under construction, the Ye-U Canal, are situated.

Another work of particular interest is the Divi Island Project in Madras, which constitutes the first attempt made in India to effect irrigation on a large scale by pumping. Divi is an island in the delta of the Kistna River with an area of over one hundred and fifty square miles or about one hundred thousand acres. Its soil is fertile and, provided water can be supplied, is in every way suitable for rice cultivation. Attempts have, indeed, been made since very early times to irrigate the island by means of tanks and inundation canals, but these sources were, at best, precarious, and success depended on certain favourable conditions of river floods which did not always obtain.

The present project comprises a pumping installation consisting of nine double-cylinder 160 horse-power Diesel engines, each driving a centrifugal pump capable of discharging 73 cubic feet of water a second on a 12-feet lift, the water being delivered into a canal system consisting of 26 miles of major channels, 24 miles of main distributaries and 116 miles of minor distributaries. The total estimated cost of the complete scheme is £200,000 on which a return of 7½ per cent. is anticipated, 48,000 acres being the area

eventually to be irrigated. The project is frankly of an experimental nature, and not only does it promise to yield a good return on the capital invested but the experience gained will prove extremely useful should the necessity arise for dealing with similar proposals from other parts of India.

CHAPTER X

PROTECTIVE WORKS OF THE PRESENT CENTURY

THE main function of the Indian Irrigation Commission was to report on the desirability of the extension of irrigation as a means of protection against famine. This function was clearly enunciated in the Government Resolution convening the Commission, of which the following is an extract:—" In considering proposals for new irrigation works the Commission will understand that greater importance may often be attached to the extent and reliability of the protection that will be afforded than to the merits of the schemes regarded as financial investments. The irrigation works hitherto constructed by the State in India have on the whole proved directly remunerative; but it is recognized that the programme of works of this kind may be approaching completion, and that the great storage works required for any considerable extension of irrigation in the tracts which are most exposed to famine must necessarily be more costly per acre protected, and therefore less remunerative, than the completed works which draw unfailing and perennial supplies from the great rivers in Northern and Southern India. As regards new works, therefore, the main question is not whether they will be likely to prove directly remunerative, but whether the net financial burden which they may impose on the State in the form of charges for interest and maintenance will be too high a price to pay for the protection against famine which they may be relied on to afford. It is from this point of view that the Commission should consider proposals for the extension of irrigation in districts in which cultivation is very insecure and precarious." In view of these instructions it is not surprising that the main energies of the Commission were devoted to the investigation of new protective projects. How far their recommendations have been carried out the following figures will show. In April 1903, when the Commission's report was signed, nine protective works were either in operation or under construction, the total capital outlay incurred on such works on that date being £2 million. By April 1921

no less than 52 protective schemes were either in operation or under construction and the capital invested in them had risen to £11¾ million, which will be increased to at least £13½ million when the works now being built are completed.

Considerations of space will not permit of more than an outline being given of the works undertaken. In view of their unproductive character there was a tendency, at the outset, to restrict projects of this nature to such as did not involve excessive capital outlay, the money available, which under the rules then in force had to be met from current revenues, being limited. Five of the works completed since the beginning of the century may be classed as of considerable magnitude, having cost between £400,000 and £1 million each; the remainder are smaller works but are collectively of the first importance as mitigating the effects of famine over wide areas.

The first canal of this nature to be completed since 1900 was the Tribeni Canal in Bihar and Orissa, followed shortly afterwards by the Girna Left Bank Canal in the Bombay Deccan. The Irrigation Commission paid special attention to the needs of the latter tract and strongly recommended the initiation of new schemes to protect what is one of the most precarious portions of India. Of the three larger works which have been taken in hand as a result of this recommendation two are, owing to their great magnitude, still under construction, and an account of them will be found in Chapter XI; the third, the Godávari Canal, was completed in 1916.

The Godavari Canals Project has as its object the irrigation of a precarious tract in the Nasik and Ahmednagar Districts. The scheme comprises a large storage reservoir of 8,800 million cubic feet capacity, known as Lake Beale, on the Darna River, a tributary of the Godavari, about twenty miles distant from Nasik, from which water is escaped down the river as required and again impounded by a pick-up weir on the Godavari at Nandur Madhmeshwar, some 47 miles below Lake Beale. Two canals draw off the

water at the Nandur Madhmeshwar weir, one, 69 miles long, on the right bank, and one, 48 miles long, on the left. The dam which forms Lake Beale is 4,480 feet long, but including the waste weir, which is fitted with fifty automatic gates each 10 feet wide, the total length of the structure is rather more than a mile. It has a maximum height of 82 feet above the river bed and of 92 feet above its lowest foundations.

The total cost of the complete scheme is £1 million. Fifty thousand acres are irrigated annually and it is estimated that, eventually, a return of 5 per cent. on the capital outlay will be realized. The work has been built primarily as an insurance against famine, but there seems every likelihood of its proving a sound productive work.

Another area to the necessity for the protection of which the Irrigation Commission directed special attention is that lying to the south of the Jumna and Ganges in the United Provinces. The geological formation of this area is much more nearly akin to the rock formations of Central India than to the alluvial formations met with throughout the rest of the province, and the whole tract is liable to extreme vicissitudes of rainfall. The annual average is from 30 to 40 inches, but the actual rainfall varies between one-third and twice the normal, and either excess or deficiency is liable to lead to scarcity and famine. During the famine of 1896-97 the expenditure incurred by Government on relief in all forms in the four districts of Bundelkhand amounted to over £1 million, and, in the Banda district, which was the most severely affected of all, over 42 per cent. of the population were at one time in receipt of relief.

At the time when the Commission reported, the only large irrigation work in this portion of the province was the Betwa Canal, but since then great activity has been displayed in the matter of the initiation of new projects. Six new protective works and one classed as productive have already come into operation, four are under construction and several more are still in the project stage.

Of these works the most important are the Ken and Dhasan Canals, each provided with two large reservoirs formed by massive masonry dams ranging from 26 to 54 feet

in height, and the Ghagar Canal, with its reservoir of more than 5,000 million cubic feet capacity at Dhandraul. The Dhandraul Dam is situated 70 miles from the nearest railway, in inaccessible country where there were no roads worthy of the name and where, in the hot weather, water was so scanty that it often had to be carried for miles to the site of the various works. In such circumstances the construction of the dam and canal was a matter of extreme difficulty. The work was completed in 1918, and is now proving its value to a large area which was formerly so precarious that the average annual cost of famine relief actually exceeded the annual collections of land revenue.

So far no reference has been made to irrigation in the Central Provinces, as prior to the commencement of this century no State works had been constructed there. A long succession of favourable years had given the impression that the province had more to fear from excessive rainfall than from drought. Between 1862 and 1897 such an occurrence as a complete failure of the monsoon was practically unheard of and the Famine Commission of 1880 reported that in the greater part of the country the rain had never been known to fail and that no part of India was freer from the apprehension of the calamity of drought than the Central Provinces. The cycle of dry years which commenced in 1897 and culminated in the famines of 1899-1900 and 1902-03 found the cultivators absolutely unprepared. Only 7½ per cent. of the crops had any means of irrigation whatsoever and consequently, during the famine of 1899-1900, nearly a quarter of the whole population of the province were in receipt of relief, £1⅔ million being spent in gratuitous relief and £2⅔ million on famine works. The necessity for irrigation was completely established and a considerable amount of work has since been undertaken to meet this need. In addition to the four major projects, the Mahanadi, Weinganga, Tandula and Kharung Canals, which are now under construction and are referred to in Chapter XI, a large number of smaller schemes have been built which, by storing the rainfall and making water available throughout the irrigation season, are doing much to stabilize the cultivation of the province.

CHAPTER XI

Works Under Construction

The largest scheme at present under construction is the Sutlej Valley Project in the Punjab. This project is the direct outcome of the great Triple Canals Project which was described in Chapter IX, where it was explained that one of the chief reasons for executing that scheme on the lines eventually adopted was to conserve the Sutlej water for the further development and extension of irrigation on either side of the river. It is with the water thus conserved that the irrigation from the Sutlej Valley Project will be effected.

To understand the scheme, it is necessary to realize the conditions at present prevailing in the Sutlej Valley. There are, on either bank of the Sutlej, both in the Punjab and in the Indian State of Bahawalpur, long series of inundation canals, which draw their supplies from the river whenever the water level is high enough to permit of it. These canals are liable to all the drawbacks which invariably attend inundation irrigation. There are no weirs at their heads and, in many cases, no means of controlling the volumes entering them ; consequently, while a supply is assured in a normal year during the monsoon months, it is liable to serious fluctuations according to the seasonal conditions. In a year of inferior rainfall little water enters the canals ; in a year of high supplies they are liable to grave damage by floods. Generally speaking, they commence to irrigate during May, when a small supply is usually received ; by September the volume has, in a normal year, fallen once again to an inconsiderable quantity. But, even in these adverse conditions, these works are of great value and irrigate an average area of no less than a million and a half acres in the tract to be commanded by the Sutlej Valley Project.

The object of the project is threefold. Firstly, it is proposed, by the provision of weirs and head regulators, to afford to the existing canals a controlled supply from the beginning of April to the middle of October, rendering them immune from the present detrimental effect of

seasonal fluctuations in the water level and thus converting them from the status of inundation to that of non-perennial canals, by non-perennial canals being understood canals to which a supply is assured during the hot weather and monsoon, though they are closed during the cold weather, when the volume in the river is low. Secondly, the areas irrigated by the existing canals are to be extended so as to embrace the whole low-lying area in the river valley. Thirdly, perennial irrigation, that is to say, irrigation throughout the year, will be given to large tracts in the uplands on either bank, in the Punjab on the north and in the States of Bahawalpur and Bikaner on the south, these tracts being at present entirely unirrigated and, in consequence of the very low rainfall, waste. The system of dividing the irrigation into perennial and non-perennial ensures the best use being made of the water available. Only 7,000 cubic feet a second are required during the cold weather, when the supplies are low, whereas a maximum of 48,500 cubic feet a second will be drawn off during the hot weather and monsoon when, owing to the melting of the snows and the rainfall in the catchments of the rivers, water is plentiful.

The project consists of four weirs, three on the Sutlej and one on the Panjnad, as the Chenab is called below its junction with the Sutlej, with twelve canals taking off from above them. This multiplicity of weirs and canals may seem to be a peculiar feature of the proposals unless the immensity of the whole scheme is considered. The project really consists of four interconnected systems, each of the first magnitude; each weir will control about one and a quarter million acres of irrigation, the total annual irrigation from all the weirs being nearly three times that contemplated under the Triple Canals Project, the largest system constructed in India up to date.

The total area to be irrigated from the project is 5,108,000 acres, or nearly 8,000 square miles. Of this, 2,075,000 acres will be perennial and 3,033,000 acres non-perennial irrigation. 1,942,000 acres will be in British territory, 2,825,000 acres in Bahawalpur and 341,000 acres in Bikaner.

The total cost of the project is estimated at £14½ million. Upon this a return of 12¾ per cent. is anticipated from water rates alone. But the scheme has another, and even more important source of revenue. On the introduction of irrigation, no less than 3¾ million acres of desert waste, the property of the three parties concerned, at present valueless, will become available for colonization and sale. It is customary, in the *pro forma* accounts of irrigation projects, to credit a scheme with the interest on the sale proceeds of Crown Waste lands rendered culturable by its construction ; if this is included, the annual return on the project will amount to nearly 38 per cent. It bids fair, indeed, to rival the Lower Chenab Canal, the return from which during the past seven years has averaged over 41 per cent.

Another project of the first magnitude now under construction is that for the Sarda Canal and Sarda Kichha Feeder in the United Provinces, the receipt of the Secretary of State's sanction to which settled finally what has been, perhaps, the most contentious question in the history of irrigation in India. "There is probably no scheme for the introduction of canal irrigation into any part of India," reported the Irrigation Commission of 1901-03, "which has formed the subject of so much discussion as that for a canal from the Sarda River for the irrigation of Oudh. Nor has any more difficult problem been laid before us during the course of our enquiries than that of deciding whether the numerous objections which have been raised against the scheme are sufficient to prevent the utilization, in the Ganges-Gogra watershed, of the enormous volume of water which now runs to waste in the Sarda River."

It is now fifty-one years since the first scheme for the irrigation of Oudh from the Sarda was put forward, and since then project after project has been prepared, only to be rejected with monotonous regularity. The main factor in the case was, throughout, the opposition of the Taluqdars, or landed proprietors of Oudh, who for years refused to have anything to do with the scheme in any

form. The Irrigation Commission recognized the impossibility of introducing canal irrigation in a tract where the feeling against it was so strong, and while not ready to admit that there were any reasons for believing that the canal would be detrimental on either agricultural or sanitary grounds, recommended the investigation of an alternative proposal for the diversion of the Sarda water into the Ganges, thereby giving a large additional supply to the existing Ganges and Agra systems, and, by means of a separate feeder from the Ganges Canal, to the Eastern and Western Jumna Canals also.

This recommendation resulted in the preparation of the so-called Sarda-Ganges-Jumna Feeder Project, the main item in which was a canal from the Sarda to the Ganges, traversing at right angles the whole of the drainage of the submontane tract between the two rivers. Had this scheme been constructed, it would probably have ranked among the engineering wonders of the world. No less than 65 rivers and drainages had to be crossed in the 159 miles of the canal, their discharges aggregating more than a million cubic feet a second. The works included four great level crossings, eleven aqueducts, fourteen syphons carrying the canal, which was to be 220 feet wide at the head and to carry 5,600 cubic feet a second, under rivers, and thirty-six syphons carrying rivers and drainages under the canal.

While, however, this project was under consideration, unmistakable signs were evinced of a change of feeling in Oudh. The Taluqdars were gradually beginning to realize that, with the ever-increasing cost of labour, well irrigation was no longer profitable, and that their crops were greatly inferior to those grown in similar tracts irrigated by the Ganges and Jumna Canals. The lesson was sharply accentuated by the occurrence of a year of short rainfall in which there was a serious shortage of crops, wells failed, and actual famine was averted only by the antecedent prosperity of the people, several districts, which had previously been regarded as immune from famine, being on the brink of serious distress. The result

was that the Taluqdars completely abandoned their former attitude and expressed a unanimous desire for the introduction of canal irrigation into Oudh. In consequence the Sarda-Ganges Feeder Project was dropped (it had always been recognized as at best an inferior substitute for the utilization of the water in the tract to which it geographically belonged) and the preparation of a comprehensive scheme for Oudh was taken in hand.

The scheme consists of two parts, the Sarda Canal proper and the Sarda Kichha Feeder which leaves it at about the seventh mile. The former comprises a comprehensive project for the irrigation of the north-western districts of Oudh, while the latter will assure a supply to' and admit of the extension of, the existing Rohilkhand Canals. The headworks and the first seven miles of the canal are common to both projects ; below the bifurcation the Sarda Canal runs in a southerly direction, while the Feeder flows westwards across the Tarai, the low-lying land at the foot of the Himalayas.

Viewing the Sarda Kichha Feeder and the Sarda Canal as a single scheme, as in effect they are although sanctioned as two separate but dependent projects, the total cost will be £9½ million, the area to be irrigated annually 1,713,000 acres and the net return anticipated over 7 per cent.

Two great reservoir projects, the Pravara and Nira Right Bank Canal Projects, are at present under construction in the Bombay Deccan. Prior to the initiation of the Pravara River Canals Project, irrigation from the Pravara River, a tributary of the Godavari, was confined to that effected by the Ojhar Left Bank Canal. This canal draws its supply from the Pravara at Ojhar, some forty miles north-west of Ahmednagar in the Bombay Presidency, where a masonry weir, some 29 feet in height, was constructed in 1873. A Right Bank Canal, with its off-take at the same point, was excavated between 1899 and 1902 with the object of affording work to famine relief labour, but was left incomplete and devoid of masonry works. In

a good year the Left Bank Canal irrigates upwards of 10,000 acres.

The main feature of the new project is an enormous masonry dam, 270 feet high, at Bhandardara in the Western Ghauts. At the point selected the Pravara passes through a wedge-shaped gorge, an ideal site for a dam, especially as the rock in both the bed and sides of the gorge is of the hardest trap. The dam is not only much the highest which has yet been constructed in India, but when completed will, it is believed, be the highest in the world in point of depth of water stored ; higher dams have been built in America, but their height includes great depth of foundation below ground level which, owing to the excellence of the rock, are unnecessary at Bhandardara. A waste weir discharging into an affluent of the main river, with its crest ten feet lower than the top of the dam, has been excavated in a neighbouring saddle ; the lake, known as Lake Arthur Hill, has a capacity of 10,800 million cubic feet and, should further storage be required at some future date, the supply can easily be raised to 12,900 million cubic feet by fitting gates on the aste weir.

The catchment area of the reservoir is only 47 square miles, but is subject to torrential rainfall, averaging from 150 to 300 inches per annum in various portions of the catchment. A further peculiar feature of the lake is the fact that the waterspread extends right back to the precipice which forms the western edge of the ghauts. At one place, indeed, the water level of the reservoir is higher than the top of this precipice and it has been necessary to erect a short length of earthen embankment to prevent the top ten feet of the water stored from cascading backwards, in a waterfall 2,000 feet high, into the Konkan.

The construction of the dam has been attended with considerable difficulty. There was no sand available for the mortar and consequently rock crushing had to be resorted to for this purpose, the lime had to be carried great distances from the surrounding country, while the

nearest railway was 21 miles away, the only connection being a zig-zag mountain road. In such circumstances the laying of the 12 million cubic feet of rubble masonry of which the dam is composed has proved a very arduous task. In addition to the construction of the dam, the existing weir at Ojhar has been raised, the upper reach of the Left Bank Canal widened and extended and the Right Bank Canal completed. The Left Bank system comprises 48 miles of main canal and 161 miles of branches and distributaries, the corresponding figures for the Right Bank system being 33 and 56 miles respectively.

The project protects a considerable area in the Ahmednagar District, a tract which is generally hard hit in years of short rainfall. The cost of the work is estimated at £1½ million ; 57,000 acres are to be irrigated and a return of 6·72 per cent. upon the capital expenditure is anticipated, a very satisfactory result for a protective work.

Good progress has been made on the dam, which has already risen to well above the 200 feet level, and the water impounded by the unfinished work is being utilized for irrigation ; it is anticipated that the whole scheme will be completed in 1923.

Like the Pravara Project, the Nira Right Bank Canal scheme is one for the remodelling, enlargement and improvement of existing works. These consist, in the latter case, of a storage reservoir, Lake Whiting, situated on the Yelwandi River, a tributary of the Nira, and of a Left Bank Canal drawing off its supply from a pick-up weir on the main river at Vir. The Right Bank Project has for its object the enlargement of the storage on the Yelwandi, and the construction of a new canal on the right bank of the river. It was also intended, when the project was framed, to remodel the Left Bank Canal, but work on this portion of the scheme is held in abeyance until the final policy in respect of the irrigation of the whole Nira Valley has been settled.

The original intention was to raise the existing Lake Whiting Dam at Bhatghar by building the new

masonry against the masonry of the old work. During construction, however, it was decided, on technical grounds, to build an entirely separate dam a little lower down the river than the existing one. The storage obtained in the reservoir thus formed will be 24,300 million cubic feet, this being the largest reservoir yet constructed in British India, while the dam, when completed, will rank among the greatest in the world, the structure comprising 21½ million cubic feet of masonry. This is, it is believed, greater than the masonry contents of any dam yet built, not excluding the Assuan Dam in Egypt. The maximum height of the existing Lake Whiting Dam is 127 feet; the new dam will be sixty feet higher and will have a length of over a mile.

The construction of the work has been greatly facilitated by the existence of the old Lake Whiting Dam. This enables the new work to be carried on below it without interference from floods, and advantage has been taken of the water stored in the old lake to instal a hydro-electric plant which drives the machinery utilized in the construction of the new dam.

The Right Bank Canal, which is 109 miles long, commands an area of 560,000 acres, of which 132,000 acres are to be irrigated annually. The revised estimate of the cost of the scheme amounts to £5 million. The work, when completed, will be of great value as protecting a considerable portion of the Sholapur District, one of the most frequently famine-stricken tracts in India.

Four large projects are under construction in the Central Provinces. The Mahanadi Canal is designed to protect a considerable area in the Raipur District. The famine history of this tract is worse than that of any other portion of the province. In 1896-97 famine occurred in the district and crops to the value of nearly £2½ million were lost, followed by an even greater loss, estimated at £3 million, in the famine of 1899-1900. In the latter year £1¼ million were expended by Government on relief in the Raipur District alone. There was severe scarcity in 1902-03

which amounted, in some parts of the district, to actual famine; two years later there was again a serious shortage and three years after that a further extensive crop failure took place. In favourable years the tract is extremely fertile, so the need for irrigation was clearly established. Being essentially a rice-growing country, a failure of the rains spells complete loss of crops and consequent widespread disaster.

The project was sanctioned in 1911 and work commenced in 1912. The works comprise a canal with its head at Rudri, where the Mahanadi has been spanned by a masonry weir, and a subsidiary reservoir at Maramsilli, formed by an earthen embankment 83 feet high and 1½ miles long, on a tributary of the Mahanadi. The distribution system, when complete, will consist of 195 miles of main canal and branches and 741 miles of distributaries. The project is estimated to cost £1½ million and 300,000 acres will be irrigated from it.

The Weinganga Canal is being constructed to irrigate portions of the Balaghat and Bhandara Districts, a tract which is liable to persistent and continuing shortage of rain even when the precipitation in the districts as a whole is sufficient to avert serious failure. The scheme consists primarily of a main canal, with two branches and their necessary distributaries, taking off from the Weinganga River, and a supplementary reservoir, known as the Sarathi Reservoir, which maintains the supply in the lower reaches of the system. The main canal is 28 miles long, and is replenished from the Sarathi Reservoir by means of a feeder channel which joins it at the eighteenth mile. The two branches aggregate about 50 miles in length.

The total estimated cost of the project is £500,000, and 91,500 acres will eventually be irrigated from it.

The Tandula Canal is a protective scheme for the irrigation of part of the Raipur and Drug Districts. It depends for its supply upon the two rivers Tandula and Sukha, which are dammed near their confluence. The

reservoir thus consists of two separate portions, one on the Sukha and the other on the Tandula, connected by a conduit excavated through the intervening spur, on which is situated the waste weir and spill channel for both reservoirs. Both dams are of earth, that on the Sukha being more than 1½ miles long, while that on the Tandula is about 1¼ miles in length. The maximum height of the dam, from foundation to crest, is 110 feet and the twin reservoir is capable of storing 9,000 million cubic feet of water above the level of the irrigating sluices.

The scheme is now approaching completion, and the new reservoir has already withstood satisfactorily a very severe test in the shape of a heavy flood caused by a fall of 21 inches of rain in 66 hours. Irrigation has been in progress from the incomplete work since 1916-17 and has risen from 1,899 acres in that year to 91,500 acres in 1920-21. The project shows every sign of successfully effecting the object with which it was designed.

The project for the Kharung Tank in the Bilaspur District of the Central Provinces has recently been sanctioned by the Secretary of State. The estimate provides for the construction on the Kharung River of a large storage reservoir of 5,560 million cubic feet capacity, and for the distribution of the water impounded by means of two canals, one on each side of the river valley. The scheme is estimated to cost £600,000 and an area of about 95,000 acres will be irrigated from it.

CHAPTER XII

PROJECTS

By far the largest project at present under consideration is that for the Sukkur Barrage and Canals in Sind. As has already been explained, Sind depends for its irrigation at present upon inundation canals from the Indus, the supply of which canals fluctuates daily with the rise and fall of the water level in the river, there being no means of regulating this level artificially as is done in the case of all the other great canals of India. When the Indus is in flood, the inundation canals obtain a full supply; when it falls in the cold weather, only the most fortunately situated obtain any supply at all and a minimum of 20,000 cubic feet of water a second runs waste to the sea. The majority of the channels commence to flow, in an average season, at about the beginning of June and cease to flow early in October; that is to say, they obtain water, and that only in fluctuating quantities, for some four months during the monsoon. The object of the Barrage Project is to afford to the country irrigated an assured supply throughout the whole year.

This is to be accomplished by constructing a barrage across the Indus below Sukkur, where the river passes through a deep gorge. The site chosen is some three miles downstream of the gorge and from this point seven canals, four on the left bank and three on the right, will run southwards, taking up the irrigation at present effected from the existing inundation canals and extending facilities for cultivation to an enormous area at present waste. The barrage will consist of a masonry floor across the river, at a level somewhat lower than the average level of the river bed, above which an overbridge of 66 spans, each of 60 feet width, will be constructed. From this overbridge shutters, 60 feet long and 18½ feet high, can be lowered on to the floor when the river falls, thus ponding up the water to the level required in the canals; conversely, when the river rises they can be lifted and the whole of the water-way of the bridge left free for the passage of floods.

The barrage, when completed, will be the greatest work of its kind in the world, measuring 4,725 feet between the faces of the regulators on either side. The supply required by the whole system of canals varies throughout the year from 22,656 cubic feet a second in January and February to 45,926 cubic feet a second from June to September. The total cost of the scheme is estimated at £18⅓ million, of which the barrage accounts for about £5⅝ million and the canals for £12⅝ million. A gross area of 7½ million acres is commanded, of which 6½ million acres is culturable, and an annual area of irrigation of 5⅓ million acres is anticipated, of which 2 million acres represents existing inundation irrigation which will be given an assured supply by the new canals. The ultimate annual net revenue forecasted as obtainable from the project, after paying working expenses, is nearly £2 million, which represents a return of 10½ per cent. on capital. This is the return from water rates alone, but a further large increase in general revenues may safely be reckoned upon from the area of 3⅓ million acres of waste which will be brought under cultivation. There will be increases on this account under practically every head of revenue, such as railways, customs, stamps, excise and the like, not to mention the addition to the country's wealth owing to the production, on land at present barren, of crops to the value of £25 million per annum.

The project has been approved by the Secretary of State in so far as its administrative and technical aspects are concerned but final sanction has been deferred pending the settlement of arrangements for the financing of the work.

Another project which has been sanctioned but the construction of which has, owing to financial stringency, not yet been commenced, is that for the Damodar Canal in Bengal. This scheme is designed to provide water partly for irrigation and partly for sanitary purposes, *e.g.*, the supply of drinking water and the flushing of old river beds. It will cost £700,000 and will irrigate 200,000 acres.

Coming now to projects which have not yet reached the stage of submission for sanction, the Punjab, of all the

provinces, has the largest number under consideration. The Thal Project is being prepared with the object of irrigating the great watershed lying between the Jhelum and the Indus with water from the latter river; an area of 1,850,000 acres, most of which is at present waste, is to be irrigated, the capital outlay being roughly estimated at £9½ million. The Bhakra Dam Project contemplates an enormous dam, 395 feet high, to store 120,000 million cubic feet of water on the Sutlej where it emerges from the hills and a new canal, taking off the river below Phillour, to supplement the supplies of portions of the existing Sirhind and Western Jumna systems and to extend irrigation into new tracts. The project raises several difficult technical questions connected with the foundations of the dam and the rate at which the reservoir will silt up, and it is impossible at present to say whether or not it will materialize. A rough estimate places the cost of the scheme at £14½ million and the area to be irrigated by it at two million acres. The Haveli Project is a useful scheme for a weir on the Chenab, below its junction with the Jhelum, with canals on either side. The fourth project under consideration is for a barrage on the Woolar Lake in Kashmir to augment the winter supply of the Jhelum for use on the Punjab Canals.

Several large projects are under consideration in Madras, the most important being the Cauvery Reservoir Project. This provides for a dam, with a maximum height of 201 feet, at Metur on the Cauvery, to store 80,000 million cubic feet of water, and for a canal 88 miles long, with a connected distributary system, taking off from the right bank of the Cauvery at the Grant Anicut. The project is estimated to cost about £5½ million; it contemplates the complete control of the present fluctuating supplies to the Delta and an area of 300,000 acres of new irrigation. A further project for a great dam on the Kistna, to store 163,000 million cubic feet of water, at a cost of about £8½ million, has been prepared in detail but is held in abeyance until the Cauvery Project, which is the more promising of the two, has been put in hand.

In the Bombay Deccan, a project has been prepared, known as the Gokak Canal Extension Project, for a dam

about 100 feet high at Daddi on the Ghatprabha and for a canal, 75 miles long. One hundred and thirty-two thousand acres are to be irrigated from the project. An estimate for the scheme, amounting to £2 million, has actually been sanctioned by the Secretary of State but this amount is known to be too low and the estimate will be revised and resubmitted before work is commenced.

In the Central Provinces, eleven large projects are under investigation. The largest, the Hasdeo River Project, will probably cost some £3 million and irrigate a quarter of a million acres, while the estimates of five of the others, the Arpa, Bagh and Dudhi River Projects and the Maniari and Ajar Hap Tanks are expected to work out at between half a million and a million pounds each. The eleven projects contemplate a total area of new irrigation of 700,000 acres.

The United Provinces Government have commenced the investigation of a scheme for a Lower Sarda Canal, including a feeder to the Sarda from the Gogra or Girwa, but this has not advanced sufficiently far to enable any opinion to be expressed as to its possible merits. Four large projects in Bundelkhand are also under consideration, these embracing the extension of the Dhasan Canal across the Barma River, the provision of a third dam and reservoir on the Betwa, at Kaprar, and the construction of two new canals, the Ohen and Paisuni Canals, in the Banda District.

In Burma, a project for embanking the left bank of the Irrawaddy River in the upper delta for 120 miles from Tullokmaw to Yandoon has been prepared, with the object of protecting, at a cost of some £600,000, about half a million acres from floods, and a couple of small canal schemes are also under consideration. Several projects are being investigated in Bihar and Orissa but none of them have yet reached the stage where estimates of expenditure and revenue can be prepared.

CHAPTER XIII

CONCLUSION

An attempt has been made in this outline to describe briefly the progress of irrigation in India. It has been shown how the old indigenous works were first dealt with and how, profiting from the lessons learnt thereon, the early British engineers conceived the idea of new and greater works, both in the matter of the harnessing of rivers and of canal construction proper; the schemes which resulted still hold their own among the largest and finest in the world. Then followed the days of megalomania, and the proof, in the failure of the Madras and East India Irrigation Companies, that much more is required in an irrigation project than a supply of water and a tract of land into which it can be diverted. These failures did not, however, hamper progress; indeed, by instilling the need for caution in the estimates both of expenditure and revenue they probably had a beneficial effect; and immediately upon them came further large and successful works, including the first great dam project and the first canal constructed primarily for the pacification of lawless tribes. The next important innovation was the acceptance of the policy of constructing financially unproductive works in order to mitigate the effects of famine. Then followed perhaps the most remarkable development of all, the utilization of irrigation for populating waste tracts, as evidenced by the Punjab Colony Canals. And so progress has steadily continued until to-day the works under construction and the projects under consideration are on a scale never before dreamt of.

It is difficult to describe what its irrigation works have meant to India. To say that 28 million acres are, or that 40 million acres will in the near future be, irrigated conveys but little idea. As has already been stated, the area irrigated in any one year is not a fair criterion, as the benefits of irrigation extend far beyond this, and for every acre so irrigated another acre or acre and a half is irrigable and will receive water in succeeding years while that irrigated previously lies fallow for a time or is sown with some drought-

resisting crop. It is not too much to say that the Government works render over a hundred thousand square miles of precarious country, which otherwise would be in continual dread of famine, certain of their crops, and that this area will be increased by over 50 per cent. when the great projects now under construction or about to be constructed are finished. Of this area, huge tracts would, but for the canals, be barren waste. In 1920-21 the value of the crops irrigated was no less than £156 million, exactly double the capital cost of the works. Most of these crops could never have been brought to maturity without irrigation and a considerable proportion of them was raised on land upon which, but for the canals, not so much as a blade of grass would grow.